



DOCUMENT RESUME

ED 167 415

SE 026 829

AUTHOR McKlveen, John W., Ed.
TITLE Energy in Perspective: An Orientation Conference for Educators. Proceedings of a Conference (Tempe, Arizona, June 7-11, 1976).
INSTITUTION Arizona State Univ., Tempe, Coll. of Engineering and Applied Sciences.
SPONS AGENCY Energy Research and Development Administration, Washington, D.C.
REPORT NO CONF-760677
PUB DATE Dec 76
CONTRACT ERDA-EY-76-C-02-2937.000
NOTE 665p.; Photographs may not reproduce well
AVAILABLE FROM National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161 (microfiche \$3.00; paper copy \$16.25)

EDRS PRICE MF-\$1.16 HC-\$35.49 Plus Postage.
DESCRIPTORS Electricity; *Energy; Energy Conservation; *Environmental Education; Fuel Consumption; *Fuels; *Futures (of Society); Health; Natural Resources; Nuclear Physics; Radiation; *Science Education; Scientific Concepts; Solar Radiation; Technological Advancement

ABSTRACT

The conference goal was to provide educators with knowledge and motivation about energy in order to establish an awareness of it in their classrooms. Speakers were from universities, research laboratories, utilities, government agencies, and private businesses. Coal, gas and oil, geothermal and solar sources of energy in Arizona were each discussed by different experts. Several of the presentations dealt with nuclear energy from nuclear theory to specific applications with discussions of safeguards, waste disposal alternatives, and economic considerations. Other speakers described the use of nuclear physics in fine arts, archeology, agriculture, and criminology. (TM)

* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *

CONF-760677

ENERGY IN PERSPECTIVE

PROCEEDINGS OF AN ORIENTATION CONFERENCE FOR EDUCATORS

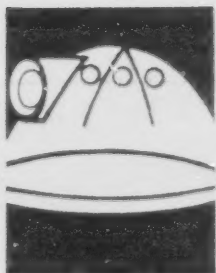
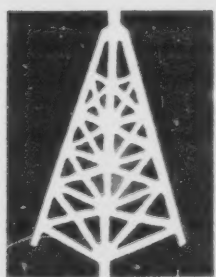
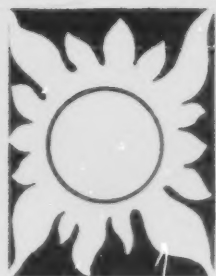
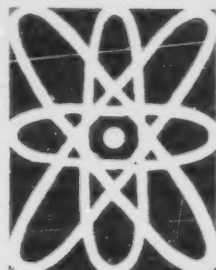
JUNE 1976

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY.

COLLEGE OF ENGINEERING AND APPLIED SCIENCES
ARIZONA STATE UNIVERSITY
TEMPE, ARIZONA 85281

FUNDED BY THE UNITED STATES ENERGY RESEARCH AND DEVELOPMENT
ADMINISTRATION IN COOPERATION WITH ASU UNIVERSITY EXTENSION



ED167415

SE 026 829

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161

Price: Paper Copy \$16.25 (domestic)
\$18.75 (foreign)
Microfiche \$3.00 (domestic)
\$4.50 (foreign)

E N E R G Y I N P E R S P E C T I V E :
A N O R I E N T A T I O N C O N F E R E N C E F O R E D U C A T O R S

**Proceedings of a conference held on June 7-11, 1976
in Tempe, Arizona, under the sponsorship of the:**

**Energy Research and Development Administration
Arizona State University College of Engineering and Applied Sciences
Arizona State University Extension Programs**

December 1976

Partially funded under ERDA Contract No. EY-76-C-02-2937.*000

Edited by:

**John W. McKlveen, Assistant Professor
College of Engineering and Applied Sciences
Arizona State University
Tempe, Arizona 85281**

ACKNOWLEDGMENT

On behalf of the University, I wish to express sincere appreciation to the Energy Research and Development Administration for assistance in developing the conference and providing financial support; to the speakers for their presentations and subsequent papers; to the University Extension personnel for handling the administrative details; to the students who escorted and introduced the speakers; and to Ms. Charleen Hayden for her assistance in the preparation of the final version of the proceedings.

John W. McKlveen
Conference Director

FOREWORD

It is no longer possible for the educators or the general public to remain complacent about energy. We must rationally evaluate the energy situation and develop a realistic philosophy. Consideration must be given to the social, economic and biological risks of inadequate energy supplies. The decisions we make about energy will have a direct bearing on the security of our country and the world and the lifestyle of future generations.

The benefits of adequate and properly exploited energy resources will be manifested in economic growth, high industrial and agricultural productivity, improved quality of life and leisure, a more healthful environment and improved ecological conditions. Shortages, wastefulness and unnecessary resource exhaustion may eventually contribute to the degradation of mankind through political conflicts, disease or starvation and poverty. Since energy is the keystone, we must recognize TODAY that there are no energy alternatives. Every existing technology and potential future addition must be researched and implemented to the maximum extent dictated by a realistic assessment of its availability, economics, benefits/risks, environmental impact, and demand.

Energy sources and options must be understood and viewed in perspective by laymen and legislators as well as engineers, scientists and educators. It takes little effort to criticize, list problems or verbalize on methods to achieve utopia--"the great society." Moreover, we have no moral or intellectual justification for becoming obsessed with hypothetical hazards, speculation and "what if" scenarios when factual information is available to document opinion. Man's best insurance for a peaceful, productive and rewarding future rests in the assurance that individual and collective decisions made today provide the most advantageous compromise between assets and liabilities. The challenges of establishing an energy policy with realistic short and long range must be recognized and addressed by all. A logical beginning point is the classroom where knowledgeable and motivated educators can establish an awareness of energy.

Toward that end, "Energy in Perspective: An Orientation Conference for Educators" is designed to provide educators with the latest information.

JOHN W. MCKLVEEN
Conference Director
College of Engineering & Applied Sciences
Arizona State University

TABLE OF CONTENTS

FOREWARD	ii
ACKNOWLEDGMENT	iii
 ENERGY AND THE EDUCATOR	 1
Ms. Carolyn Warner, Superintendent of Public Instruction, State of Arizona	
 ENERGY RESOURCES: WORLD AND U.S.A.	 17
Dr. Gary Higgins, Technical Advisor for Energy and Resource Program, Lawrence Livermore Laboratory	
 ARIZONA'S ENERGY RESOURCES AND DEVELOPMENT	 35
Dr. William Dresher, Dean, College of Mines, University of Arizona	
 COAL TECHNOLOGY - MINING AND ENERGY CONVERSION IN THE U.S.A.	 67
Mr. C. R. Draper, Administrator, Research and Information Systems Division, Department of Intergovernmental Relations, State of Montana	
 GAS AND OIL: NATURAL GAS, S.N.G., OIL, OIL SHALE, AND TAR SANDS	 88
Mr. John Bannister, Executive Secretary, Arizona Oil and Gas Conservation Commission	
 GEOHERMAL ENERGY PERSPECTIVE	 106
Mr. Steve Rogers, Steam Generation Engineer, Pacific Gas and Electric Company	
 SOLAR ENERGY	 136
Mr. Dan Halacy, Assistant to Senator Paul Fannin	
 UTILIZATION OF SOLAR ENERGY FOR POWER	 179
Dr. Charles Backus, College of Engineering Sciences (Mechanical), Arizona State University	
 NATURAL RADIATION ENVIRONMENT	 196
Dr. John W. McKlveen, College of Engineering Sciences (Mechanical), Arizona State University	
 FISSION THEORY	 216
Dr. John Bregar, College of Engineering Sciences (Mechanical), Arizona State University	
 ARIZONA'S PALO VERDE NUCLEAR GENERATION COMPLEX	 238
Mr. Edwin Van Brunt, Director, Arizona Nuclear Power Project; Vice-President, Arizona Public Service Company	

GAS COOLED REACTORS, LIQUID METAL REACTORS AND ALTERNATIVES	259
Dr. Merwin L. Brown, Senior Research Analyst, Arizona Public Service Company	
RADIOACTIVE WASTES: DISPOSAL ALTERNATIVES	287
Dr. William Bishop, Chief, Waste Management Branch, U.S. NRC	
NUCLEAR SAFEGUARDS	306
Mr. James F. Ney, Division Supervisor, Nuclear Security System Studies Division, Sandia Laboratories	
NUCLEAR BENEFITS VS. RISKS	336
Dr. John W. McKlveen, College of Engineering Sciences (Mechanical), Arizona State University	
FUSION REACTORS AND THEIR FUEL CYCLE: A PRIMER	365
Dr. Ray Wymer, Associate Director, Chemical Technology Division, Oak Ridge National Laboratory	
GENETIC AND SOMATIC RADIATION EFFECTS	406
Dr. Gerry N. Cosgrove, Pathologist, Biologist, Biology Division, Oak Ridge National Laboratory	
ENERGY ECONOMICS	428
Dr. Claude Poncelet, Scientific Advisor, Energy Action Office, Westinghouse Electric Power Systems Company	
RELIGION, PHILOSOPHY AND ENERGY	473
Dr. William G. Pollard, Minister, Nuclear Physicist, Institute for Energy Analysis, Oak Ridge Associated Universities	
NUCLEAR STUDIES IN FINE ARTS AND ARCHEOLOGY	485
Dr. Garman Harbottle, Fine Arts and Archeological Research, Brookhaven National Laboratory	
APPLICATION OF NUCLEAR METHODS TO FOOD PRESERVATION AND AGRICULTURE	530
Dr. Edward Josephson, Honorary Lecturer, Department of Nutrition and Food Studies, Massachusetts Institute of Technology	
NUCLEAR METHODS IN CRIMINOLOGY	547
Dr. George Nelson, College of Engineering (Nuclear), University of Arizona	
HEALTH EFFECTS OF ENERGY PRODUCTION AND CONVERSION	552
Dr. Cyril Comar, Director, Department of Environmental Assessment, Electric Power Research Institute	

RISK AND INSURANCE CONSIDERATION — ENERGY FOR TOMORROW	583
Mr. Earle V. Maynard, President, Earle Maynard and Company Insurance Brokers	
ENERGY IN PERSPECTIVE	594
Dr. Norman Hilberry, College of Engineering (Nuclear), University of Arizona; Governor's Science Advisor, National Governors' Conference Energy Project; Commissioner, Arizona Atomic Energy Commission	

CONFERENCE PLANNING COMMITTEE

Dr. John W. McKlveen	Conference Director College of Engineering & Applied Sciences Arizona State University
Dr. John Bregar	Professor College of Engineering & Applied Sciences Arizona State University
Dr. Brent W. Brown	Executive Director Office of Economic Planning and Development State of Arizona Chairman, Arizona Interagency Planning Office
Ms. Polly Gallardo	Public Information Officer Arizona Atomic Energy Commission
Mr. Donald C. Gilbert	Executive Director Arizona Atomic Energy Commission
Mr. Lyman Jackson	Education Program Specialist Arizona Department of Education
Mr. Thomas Lynch	Chief, Fuel Allocation Office of Economic Planning and Development State of Arizona
Mr. Garvis Pollard	Nuclear Technology Specialist Arizona Atomic Energy Commission
Mr. Edward B. Scannell	Coordinator Continuing Education Arizona State University
Mr. Harold Young	Director of Special Projects U.S. Energy Research and Development Administration

ENERGY AND THE EDUCATOR

By
CAROLYN WARNER

**Superintendent of Public Instruction
Arizona Department of Education
1535 West Jefferson
Phoenix, Arizona 85007**

ENERGY AND THE EDUCATOR

Ladies and gentlemen, I am delighted to be here this morning. I'm always a little concerned when people ask me to speak and say, "You're going to be the first speaker. The rest of the program is entertainment." I begin to understand right away that I'd better make it quick and I'd better make it succinct and I'd better get off the program because you have things that are more entertaining to do. So in my role as State Superintendent of Public Instruction, I bring you greetings from the State of Arizona and more particularly, from the Department of Education, as a representative of or spokesman for the educators of the children of the State of Arizona and as your liaison representative to the Board of Regents and to the Community College Board. I am particularly interested in the subject, because I believe it happens to be the subject to which we must as a people, not just as educators, address our attention immediately. Why do I think it is so important and ranks so high on the list? Very simply, it is a crisis situation that we're now in and none of us are quite sure how we got into this crisis. Where were we when the decisions were being made? In our public schools, that is the groundwork, the seedbed, in which we plant the idea that develops into an eventual harvest, there is no more important place with which we should place energy as a top priority concern than in the classroom, because the teacher that we intend to send into our public schools in 1986 is

today a sixth grader somewhere out there. He or she must be taught beginning right now along with every other American girl or boy about environmental quality, about ecology, about the consumability of the resources on our planet. They must be taught now, those sixth graders, in order to be able to function successfully in that classroom ten years from now in 1986. So we not only disseminate information and assist those that are going to be our citizens, active citizens, tomorrow, but today in the classroom we build our teachers, we build our doctors, our lawyers, our scientists, our researchers, those that will apply the technology of pure science and provide us with answers. They're there, they're here, they're with us, they're our children. I see a number of teachers in this room that I know. Those teachers affect the lives of those that will be in those roles in the immediate future, not one that we can't fathom. Now, we're all realistic, we're all grown up. We know that education can't do everything. Education cannot make the sun rise. It either will or it won't. But education can let the light in, can be the way in which we raise the questions, field the problems and search for and find the answers. To our young people, I think every one of them should have an opportunity in their science class, social studies classes, their English classes, in some class in their experience in public school they should hear, understand, internalize, and hopefully empathize with the words of Frank Borman when he was out there, way out there looking back, looking back at mother earth. Now most of us haven't been off this planet. I doubt that there's anyone in this room, but he said when you're privileged to view the earth from afar, when you can hold out your hand, put up your thumb and cover it with your thumbnail, you realize that we are

really members on the space station earth. Our environment is bounded, our resources are limited, our life support system is a closed cycle, we're all in the same space ship. I find it hard to put myself in that position. I think myself to be an empathetic person, but imagine being way out there in the blackness of space looking back and seeing this planet and being able to obliterate it by closing one eye and holding up your thumb. It's hard emotionally to understand that we are behind that thumb and maybe today, maybe today, if we open up our minds we are under a thumb.

I find most creative answers to very complex problems come from the classroom, the elementary school classroom, because there they are able to synthesize into so few words the most complex of all possible concepts. Just the other day as the Governor's effort and the Department of Education's effort combined to create energy awareness among our public school students we had a slogan and poster contest. I don't know how many of you were involved in that, but some of the winners were marvelous, some of those slogans that won. But some of those that lost were absolutely spectacular. Now they were not esoteric enough to win. They didn't demonstrate all of the proper things that one would want to put out in public, but some of those answers are priceless. I've been looking for creative answers to the energy crises. I haven't been able to find them. We've been able to talk about them, we've been able to manufacture tons of material on them, but as far as creativity is concerned, let me share this with you:

"SAVE ENERGY - CUDDLE" Now I don't really know why a sixth grader submitted that, but I don't choose to go into detail.

"A KILOWATT A DAY KEEPS THE ENERGY CRISES AWAY"

"ENERGY - SAY YOU CARE AND BE AWARE"

They threw in a little environment. I think they confused the two. That's all right, because though you may smile and say they aren't on the subject, aren't they when you stop and think about it?

"SICK AIR, LET'S MAKE IT BETTER" The poster was air, a personification of air, ill, something wrapped around the head, thermometer in the mouth...sick air, let's make it better.

They really got off on ecology in "CLEAN UP, BE A MAN...PUT YOUR GARBAGE IN A TRASH CAN"

"GIVE A HAND - HELP YOUR LAND" Not bad, with an outline of a hand.

How about this? "ENERGY IS MORE FUN WHEN IT COMES FROM THE SUN" Pretty creative for a sixth grader.

Now for a third grader. Didn't know we were still teaching some of these subjects in school. "CONSERVE ENERGY - USE YOUR SOL" Soul, I suppose he was playing with.

"DON'T BE A GHOUL, WE'RE LOW ON FUEL" It's all those Frankenstein movies these kids are watching on television.

"KEEP IT COOL AND DON'T WASTE FUEL"

"COAL IS THE ANSWER - DIG IT?"

"ENERGY - KEY TO ETERNITY. CAN'T BE COPIED - DON'T LOSE IT" Not bad.

"SAVE ENERGY - INVEST IN THE FUTURE"

Grade school students in the public schools of the State of Arizona. Those are the most creative, the most creative approaches to energy conservation, to energy utilization, that I've heard or seen.

Now, I don't want to sound like an old man. I remember Joe E. Brown was asked about looking back on his life, a great long story of all his experiences. Somebody said, "Tell me how you feel about it." He said, "Well, if I had to do it all over again I wouldn't have the energy." I think maybe that relates to today and to some of the

problems we face. If we had to relive the last 25 years all over again in light of what we know today, about the fact that it is temporal this thing that we have considered everlasting, we might not have the energy, our priorities might indeed have changed. So what we teach in the classroom is vitally important. Teaching youngsters what the true story is concerning our environment, helping them to understand what Frank Borman was saying and seeing if in some way we can cause them to learn a multitude of things from the thumbnail planet that we all live upon. For one thing, it says we're all brothers. Why? And sisters. Why? No place to go. We're all going to be here spinning around together. We may as well communicate, may as well get along. It's what we teach as we look for an energy answer that's going to help us find our way out of the morass.

I heard a preacher a couple of weeks ago at a U. S. Office of Education conference that still confuses me just a little bit. But Ted Bell invited the Reverend Jesse Jackson to speak to the Chief State School Officers. Now Jesse Jackson is a mighty powerful speaker and he had one line in that speech that appealed to me and continues to appeal to me. I think it just about says it all about people and about young people in particular. He said, "It's not your aptitude, but your attitude that determines your altitude if you have intestinal fortitude." Now, we're one of the wealthiest nations in the world. Now you know you share that with young people across this state at commencement exercises and they really turn on. They begin at once to understand what the Reverend Jackson is saying and you see the expressions on their faces as they internalize that. He's not saying you've got to have an IQ of 198. He's saying it's how you feel about who you are

and what you want to be and what you want to do. It's how you have viewed yourself and the world around you, not your aptitude necessarily, but your attitude that determines where you're going to go, where you're going to peak out.

Thomas Jefferson, and I like Thomas Jefferson because he said a lot of things and he said them well, said the face and character of our country are determined by what we do with America and its resources. Now you know Tom was not talking about coal, oil, natural gas, nuclear energy; he was not talking about any of those things that we're discussing today. But he said the face and character of our country are determined by what we do with America and its resources two hundred years ago. Now we understand resources in a slightly different way. I'm always fond of the fellow who said from time to time we're reminded to look at cows and remember the world's greatest scientists have never been able to learn how to turn grass into milk. Now even that today has a double meaning and I refuse to elaborate. But if Thomas Jefferson understood and lived today he could easily make the transfer from people resources, from timber resources, from land resources, from law resources, from the concept that was America, those resources, into the emergency crisis situation of today and his statement is more true today than 200 years ago.

Now you're going to have a lot of experts speaking to you. I was mightily impressed by this program, impressed with the purpose, impressed with the speakers, and the fact that you're going to touch on all of the major areas. And you're going to leave here with a very broad and yet specific knowledge of where we are. So since I'm not a specialist, I would like to synopsise a few quick things and tell you why we've got

to carry this into the classroom. You know it. Perhaps I can view it from a slightly different perspective, but we're all talking about the same thing.

Today we look back and therein we gain our perspective. We must look back, examine our history, look to today and project into the future. If we ignore our history, the history of this problem, then perhaps we are unable to solve the problem. Since World War II, did you know that the United States has accounted for more than one-third of the world's energy consumption? One-third of the world's energy consumption we have used. You know our population and how it relates to the rest of the people that live on our planet. And that's not to say that we should not have, that's not to say that we have been selfish and used more than our share. We probably could not be the people we are or the nation we are without having done it. I'm not judging, I'm sharing. The major consuming sectors were industry. Thirty percent of the energy used since World War II was used by industry. Transportation, 26%; electric generation, generation of electric energy, 22%; household and commercial uses, 21%. Now here is the kicker. Most of this energy came from non-renewable energy resources. Non-renewable. We don't have the time. We don't have the thousands and thousands and thousands of years to recreate. We don't even have the creatures around that need to fall into those bogs and be unable to get out and die one on top of another in order to do it. Forty percent of this non-renewable energy came from petroleum. Thirty percent from natural gas; 20% from coal; 3% nuclear; 3% hydroelectric. The balance from a variety of other minor sources. Now, I know how you feel about statistics. Back at that conference Mr. Hodgkinson, of the National

Institute of Education, also made a speech and it was loaded with statistics. I was taking notes like mad of all the specifics. I forgot to put in the headings, looked at them two days later when they were cold and hadn't the foggiest notion what it was he was talking about. But one of his statistics I remember very distinctly. There was an elderly gentleman sitting right beside me, Chief State School Officer from Mississippi. Mr. Hodgkinson said that for every 77 year old man in America there are 14 women. This gentleman made a note of that. I could see he was really playing around with that idea. And then he got this worried look on his face and finally it converted into a frown and he said, "Mrs. Warner, that is the most useless piece of information I've ever heard in my life."

But not entirely leaving statistics, looking at it a little more seriously, and at the same time without going into all the background that will be provided you by experts, which I am not, I think we need to understand that all of the projections concerning energy in America, all of the projections indicate that our energy consumption will double by the year 2000. Now they've restudied that whole question since the embargo and they've reduced it slightly, but only slightly. Interestingly enough, the United States is in a particularly enviable position because we have an abundance of non-renewable energy resources, non-renewable. But during the past 25 years we have relied increasingly on imported oil. At the time of the embargo, 1973, one-third of our oil came from foreign sources. What about today? Since 1973, dependence on imports has continued to increase. Crisis situation. Black-mail is the possibility any day, every day, but we are more dependent on imported oil today than we were in 1973 when it was first called to

our attention. Our natural gas, the most desirable fuel, will run out in 20 years even with all of the new discoveries plugged in. Imagine that. We've used natural gas during our entire lifetime. It is going to run out and the scientists and the geologists tell us that even with all the new fields we can discover and put on-line as far as America is concerned our maximum is 20 years and that as a resource, like the horse and buggy, is gone. Something that we will write about and we take it so for granted. Coal, our most plentiful fossil fuel, synthetic fuel, oil, gas from shale and coal, the cost is great today. You here today, perhaps the young lady who introduced me, the students that are working with you on this conference, may find the technology to cause those costs to be reduced. Somebody must and it does not necessarily have to come out of a major lab.

Then we have nuclear energy. In 1975, the U.S. had 56 nuclear power plants in operation producing about 8% of the nation's electricity; an additional 66 under construction, an additional 110 on order. Every day more and more doubt about that 110 that are on order. Cancellations being considered. Why? Because all of a sudden somebody said, "Is it safe?" Where were we when that question should have been asked to begin with? We weren't part of the debate, but today we are. No one of us, no one of those that made the decision to place the emphasis on nuclear energy, none of them, were selfish people concerned only with their life and their lifetime. None of them intended or had any thought toward mortgaging the future of our nation, of our planet, of our children, of their grandchildren. The safety factor was one we internalized but we didn't translate into reality.

The other source, hydroelectric power. Like natural gas there is

little more we can do. It isn't finished. The rain will fall, the rivers will run, the dams will hold them, unless you're up in the Dakotas and that may not happen, the turbines will turn and we will generate hydroelectric power. But few, if any, significant potential sites remain undeveloped for future production. Perhaps we can increase the output, but there are few places in which we can now look for new sources of hydroelectric power.

Solar energy - earth's most abundant energy resource. We don't have a corner on it. We do here in Arizona, but not as a nation. Technologies for conversion of solar energy to electricity are still in the research stage.

And then we have geothermal; we have wind and ocean, heat radiance, tides, all kinds of possibilities. Wind, that one always interested me. It's a political year. I've always wondered why it was somebody since we have this energy problem didn't try to harness all of the wind that is moving around our country in a political year. It's said, I don't know whether it's true or not, that Muriel said to Hubert one time, "To be immortal you don't have to be endless." I heard about a politician and they said this particular politician spoke at 137 words per minute with gusts up to 250. Now you know wind energy research in a case like that is something worth taking into serious consideration. I remember talking about all of these potential energy resources and remembering that we're just not concentrating on one. Somebody asked a fellow which he thought was worse, ignorance or apathy. His answer was, "I don't know and I don't care." We cannot afford to be apathetic and we can no longer afford as a people to be ignorant and to say, "Somebody out there will do it for us." Because we've

already said that and by and large, they've already done it. We don't know whether it's for us or to us. But let me just tell you what it shakes out to be and I'll let you decide that. You, out of your tax dollars, are funding research and development through the Federal government in fiscal year 1976 budget to the tune of \$1.6 billion. So regardless of whether you are a teacher in a classroom or an administrator or a student at the university, you're paying your share of energy research out of your tax dollar. One hundred sixteen million dollars of that \$1.6 billion is spent for solar research and development; \$991 million for research and development in nuclear energy. Who set the priority? Did you? I don't know anyone who did. I've asked people, "Did you participate in the debate that caused us as a people to set this priority?" Everybody says, "I wasn't there." The nuclear energy research and development money, that \$991 million, is more than all the others combined; solar, geothermal, wind, conservation. My concern is where is the common sense in all of this? Do you put all of your eggs in one basket? Are we going back to the story of the little girl when we were children that started the pot of rice, the magic pot of rice, and forgot the words to turn it off and had to plow her way with a spoon on the path back to the house through the rice? Maybe nuclear energy is the answer. I don't know. Maybe you will know when this conference is over. But surely it seems to me that when you have all of the possibilities and probabilities, that as a people we might wish to spread our research and development dollars over a number of promising possibilities without the implied threat of the destruction of our children's future or our grandchildren's future. I am convinced that we must use in all

likelihood nuclear energy now because it's here and we have the technology and we can do it. But I'm not convinced that we need to continue headlong until we stop, take a look, and if we decide it's the best way to go. But I think we, common sense people who have to live in this country and on this planet, need to be part of the process. My grandmother use to teach me that the next best thing to winning is losing. She always said that at least you've been in the race. Well, if we lose on this one, I don't know that it is the next best thing to winning because this is a permanent loss. You've been in a race but what kind of a race was it you were in? Suicide race? A non-common sense race? A non-balanced race? I think it a very serious problem.

Now, you want me to close and I must. It's a very complicated matter, highly touted. None of us have all the answers, obviously. I'm reminded of Talleulah Bankhead when she met the famous Alexander Wolcott for the first time, looked over that cynical, erudite gentleman and said, "There's really less here than meets the eye." But Talleulah had a way of doing it and a way of saying it. I think there's less knowledge here than meets the eye except in one specific field in which we have invested billions of dollars, almost \$1 billion this fiscal year. Our children said and these are the winners:

"LET SOLAR ENERGY LIGHT YOUR FIRE"

"ENERGY AWARENESS IS ENERGY CARENESS"

"TURN OFF AMERICA - LIGHT UP THE FUTURE"

"NOW IS THE HOUR TO SAVE SOME POWER"

Now there's a thought. How about that? It's not going to cost us \$991 million to look at the possibility that we've always known as people who live on a family budget. One of the ways to make more money

in to spend less money. We've all learned that at one time or another. One of the ways to provide more energy is to need less energy. How much time, research, thought has gone into conservation? How many of you, like my husband and I sitting in our family room, have glanced at the wall where the brick meets the wood window frame and found that you could look outside. Now if we can look outside, I know what's happening to our refrigeration and in the winter, what's happening to our heat. Our home is poorly insulated. Our schools, by and large, are not well insulated. This energy crises is beginning to impact upon the operation of public schools and all other public institutions. Year-round school, an emerging concept both from the standpoint of new curriculum development and opportunities for teachers, has now sort of been put on a back burner. Why? Energy needs during the summer months. Many of the things we would like to do are now being put on a back burner until we find a way to be able to afford to do it. But I submit, conservation, insulation, construction for energy conservation, remodeling with energy conservation as a major component, to my knowledge has not been significantly addressed. We in the Department of Education are building a schools facility resource handbook attempting to address those various issues but in a very light way. We can't go into detail.

All right, your Alexander Wolcott was a character, as you know. One of the things he said when the speaker was going over long, he interrupted as he was want to do and he said, "My leg has gone to sleep, do you mind if I join it?" So in case some of you are having to shift around and your leg is going to sleep, I'd like to close with this little thought.

I know it's too simple to look around for a Ben Franklin and provide that young man with a kite and a key and string or wire and a thunderstorm, but I remember Ben Franklin said that the only thing more expensive than education is ignorance. That was the penny pincher of all time, Ben Franklin. We're at a place today where ignorance is not only going to be expensive, it may be fatal. I submit that this conference, that its purpose, is in all likelihood the answer that we're looking for provided the benefits are carried back and implemented

Let me close then with just an illustration of where I rather see our being today, and it frightens me, and you can move us away from that position. You're probably familiar with the research that was done by the great French naturalist with certain processionary caterpillars that feed on pine needles. It's an interesting story. I'm beginning to empathize with those processionary caterpillars, and I didn't even know that I was involved in their lifetime process. Their lifetime process is that they move through the trees in a long procession one leading, the others following, each with his head fitted snugly against the rear of his predecessor, and away they go. Well, Mr. Fabre had been experimenting with these caterpillars and he finally enticed them to the rim of a great big round flower pot where he succeeded in getting the first one connected up with the last one, thus forming a complete circle which had neither a beginning nor did it have an end. And around and around they marched around the rim of the pot. He placed pine needles inside the pot and outside on the ground so that one daring caterpillar could smell them or react to them in whatever way a caterpillar does know they're there and break the circle. Let me tell you what happened. Instead of catching on after a while, getting tired of

that useless march without beginning, without end, they saw the food, I'm sure, they certainly were aware that it was there, but it was outside of their circle. Through sheer force of habit this living, creeping circle kept moving around for seven days and seven nights until the last dropped of starvation and exhaustion. They would have been going on still had it not been for exhaustion and starvation. They mistook activity for accomplishment. They meant well, but they got no place. Do not let them, those who are observing our activities in the leadership roles that are represented in this room, ever accuse us of activity without accomplishment in an area that I believe to be a serious crisis, maybe the most serious crisis that any of us in education must ever deal with.

I commend to you your conference, your purpose; I would if I could encourage you to consider the urgency and to provide answers for people in education, so that we can disseminate. I'll be delighted to know the results of your conference and hope I'll have the opportunity of sharing the benefits with others.

Thank you very much.

ENERGY RESOURCES - WORLD AND USA

By
DR. GARY HIGGINS

**Technical Advisor for Energy and Resource Program
Lawrence Livermore Laboratory
P. O. Box 808 - L41
Livermore, California 84550**

ENERGY RESOURCES - WORLD AND USA

Thank you very much. I hope today to leave one message with you that has struck me as being a fundamental concept. The thought I want to elaborate is that all energy we use came from nuclear energy. You probably, most of you at least, have realized that. However, this is not a plea for-or justification for-nuclear reactor energy. That is not what I am saying. I'm saying all energy--solar power, fossil fuel, wind, tides and geothermal energy--is a consequence of nuclear processes.

In the first place, we know that the sun itself is a nuclear furnace. The thermonuclear cycle isn't too important except that it is a second generation. The first thermonuclear reaction very likely was much like the one that our controlled thermonuclear program will use when and if it is successful. The one that is going on now is a little more complicated. It requires higher temperatures and higher densities and hence, the quality of radiant energy from the sun is higher than it was early in the sun's history.

From the sun, we receive that nuclear energy in the form of direct radiation or warmth and from that, in turn, photosynthesis creates energy stored in plant tissue. We get fuels like wood, algae, other plants, particularly grasses and of those the canes that we harvest for sugar are very efficient in converting solar energy into fixed hydrocarbons. Another by-product of plants is oxygen. We think of oxygen produced by plants restoring the environment because we use oxygen

and it's the plants who scavenge the atmosphere for the wasteful carbon dioxide. But it is very clear now when we examine the paleogeological record that oxygen is the waste. Sometime, like 3 billion years ago, the atmosphere of the earth was comprised of carbon dioxide, methane, hydrochloric acid, water vapor and there were no animals. It was intolerable, in fact, to an animal. In that time in the soup of whatever other longer molecular weight organic compounds that existed, chemicals organized well enough to use the sun's light to capture energy and started to reproduce themselves. They found an abundance of stored hydrocarbon energy and carbon dioxide. As they made use of it, they created their waste products and polluted their environment with oxygen. In fact, can you conceive an organism creating waste that comprises 20% of the atmosphere? And that's very clearly what happened at about the time of the transition from the late Precambrian to the Cambrian age. We have records of precipitation of iron and formation of large dolomite reefs precipitated from the ocean. The waste products produced by these creatures or organisms became so abundant they literally changed the entire face of the earth. We must realize that when we talk about "the environment" we're talking about something that is a snapshot, almost a flash x-ray, a micro-instant in the evolution of the earth. If you want to restore it, which particular past would you choose? Do we want to go back a 100 years, a 1000 years, 2 million years, or a couple of billion years? You have to realize that there is no such thing as the primeval environment in which man could be happy. So, we are in a natural continuum that we and our predecessors have continually been changing. Some of the changes have been happy and others unhappy. We're intelligent enough, perhaps, not to dwell on what it

was and what we would like to preserve, but on how we would engineer it for our overall best interests.

Now let's return to the fixed hydrocarbons that the sun has been creating. We have the fossil fuel which is cellulose or carbon with water attached to it in such a way that it can yield or store energy. The sun also heats fluids covering the earth. Instabilities are created as a natural consequence of behavior of material in a gravitational field. You cannot have gravitationally stable fluid that is isothermal. In other words, if you have a column of air the compression at the bottom requires that it be hotter than the top. But the nature of thermal conductivity or temperature stability says that heat flows from hot to cold. And so the atmosphere is in an inherently unstable condition constantly trying to satisfy two mutually exclusive requirements. But they are mutually exclusive only as long as there is an external energy source--the sun. All of the winds are a direct consequence of solar energy. When we talk about "solar energy" and "wind energy", we are really talking about the same thing. When we talk about burning wood, we're talking about using solar energy. Some fraction, between 1 in 100,000 and 1 in 100,000,000 the part of each year's solar light is fixed in the form of hydrocarbon which ends up being trapped as fossil fuel. It's a constantly occurring process. It has been constantly occurring since the advent of oxygen in the atmosphere. At any time, it goes on more in some places than in other places.

Now, when animals came along and began to eat some of these cellulose or carbohydrates, they produced large amounts of other organic compounds which became fats. And those fats plus some of the plant

material and other detritus became, apparently, petroleum. However, it wasn't the familiar dinosaur of the TV ad that was important; it was probably mostly insects as nearly as we can tell from the artifacts that remain with the solids in oil field rocks. There were probably also some large animals but they were such a trivial part of the whole they didn't really count. And the fact that neither brontosaurus nor tyrannosaurus is around doesn't mean there is not a lot of oil being formed today.

Now when hydrocarbons from plant or animal get heated hot enough they partially decompose and get closer and closer to pure carbon. There are whole sequences of coal which vary in a continuum from sort of like wood all the way to pure graphite.

Geothermal energy comes from the decay of natural radioactivities left in the earth. Uranium, thorium and potassium are the three predominant ones today although earlier there were some others. It is possible to balance the sum of the heat from radioactive materials in the crust and upper mantle of the earth with the total heat flow coming out of the earth. If radioactivity went away there would be no geothermal energy. Uranium, thorium and potassium have half-lives which are comparable to the age of the earth. When the earth was formed, the radioactive heating rate was about 7 fold greater than it is today. About a hundred million years ago, water washing uranium together created a natural nuclear reactor which burned, intermittently apparently, for a number of tens or hundreds of thousands of years. It burned long enough to deplete the uranium 235 to levels which are apparent today. It left behind its fission products and plutonium which decayed to stable isotopes also detectable today. We find two things: first, the nuclear reactor

was moderated by water and was intermittent because the water would come in, the nuclear reaction would start and as soon as enough heat was generated, the water would turn to steam and bubble out. The nuclear reaction would then stop, it would cool off and the water would run back in starting the process all over. Studies of the dispersion of the fission products show that their transport in water was, at most, a few meters. I exclude the gasses from that statement because, of course, they would go with the steam. But as far as the plutonium, strontium 90 and cesium 137 are concerned there is no question that within that water system they were absorbed and stayed in the rock just as laboratory experiments suggest they should.

I bring that reactor up because I know that the issue of behavior of radioactive by-products is terribly important. Nuclear energy is not crucial in our whole spectrum of energy resources but it is crucial from the standpoint that we must consider each alternative energy resource on its own merit.

If we consider man has been around about 2 million years, more than 1 million 900 hundred thousand 800 years of that time he survived, prospered and multiplied on the current crop of organic energy. The current crop consists of wood, animal fat, fibers, the warmth of the sun itself, and the flow of heat from the earth. It's not by accident that a cave remains within a few degrees of the average annual temperature which is, in turn, the balance of geothermal heat flow, the solar input and radiation loss to space. We were cave dwellers not only because of protection from rain and large animals, but also because a cave is cooled in hot weather and heated in cold weather by the natural balance. Some of us who lived in the midwest have forgotten how nice and cool the basement

was on an August afternoon and that food stored there didn't freeze in winter.

Now, let's look at the last two hundred years. The first figure shows all of the energy we use divided up in terms of percentage. We know that the Greeks had knowledge of petroleum resources three thousand years ago. But they didn't use it. Energy came from people, chained or otherwise, who were rowing those boats and there was wind in some of the sails. Hard to believe isn't it? We knew about abundant coal for two centuries before that but it wasn't an important energy source. Most steam and iron producers used charcoal for fuel. As a result, whole regions were deforested to provide the energy for mans use. There is some evidence that many of the puebls in the southwest did not fail because of lack of food, or from enemies, or lack of water but because they burned all the trees around. Returning to Figure 1, you find that by 1880 or so wood has dropped to supply only 50% of the energy, coal about 45% and petroleum only 5%. In 1859, the first oil well was drilled in Pennsylvania. But note even 40 years later in 1900 oil still supplied less than 10% of all of our energy. It takes a long time for a new fuel to assume importance in our cultural and industrial activities. Most machines that exist are designed to use fuels that have been around a long time. A horse cannot use oil for fuel and neither can a steam engine until you redesign the coal burning fire box. That means throwing the old one away. You don't do that if you're prudent and the old one still works. There is a designed life time of machines that convert energy from one form to another and that life time is built into the economic system. Going back to Figure 1, we see that by 1950, we don't use much wood at all. Coal still accounted for 25% and petroleum for

45%, natural gas for 20%. And way up at the top are lots of little sources that sum to about 5%.

The next figure, Figure 2, shows the past and estimated future use of one fuel - petroleum. Note the shape of the curves which rise to a peak then fall to zero. Only about 1 millionth of the total hydrocarbon material which is flowing in the biosphere is side tracked into fossil fuel storage. The rate of production of fossil fuel is so much smaller than our rate of consumption that we're depleting the bank account. If you have an investment that is drawing interest you can go along and pull out of that investment a little bit each year as long as you allow for inflation and maintaining the capital reserve. But as soon as you start to withdraw the principle, not only does the principle go down but the return goes down. There is a catastrophic failure when you reach the peak and it starts down. Once it starts down there is no way to turn it around. That is a self-governing kind of catastrophe.

Now, whether or not the peaks are precise at these times is not important but the shape is. It is very clear that the generation now being born will certainly see the day when natural liquid petroleum is an uncommon product, used for antique lamps, for paraffin for sealing wax, for lubricants and as a curiosity. I don't mean to say there will not be liquid hydrocarbon fuel because there will be. It won't come from crude oil.

The oil of the Middle East occurs in wonderful deposits. The permeabilities and the reservoir pressures are such that the rate at which you can withdraw it is phenomenal. The cost of its production is almost nothing. Note how steeply the Middle East curve rises but also how steeply it falls because that's another inherent part of such an invest-

ment. The faster one withdraws the faster the account goes to zero. And so the wonderful Middle East deposits will be gone far before most of the other world's petroleum. The big ones that remain are probably in the offshore deposits of South America, Africa and portions of the Indian Ocean where the erosional deposition along with the organic material has trapped things that make petroleum just like it did where the Mississippi ran into the Gulf over Texas. Within a 100 years, we can forget oil as a major source of energy.

The next slide, Figure 3, sums up the petroleum numbers and compares petroleum with the other energy sources. All of the oil is six times less than all of the coal. It might be comforting to conclude, "Gee, we're going to use up the oil but we've got a lot of coal." Is it more comforting to say that 600 years is so long that we don't care and 100 years is so short, we do? I think not. I think if we have a lesson to learn it's from the last century when we've started depending on resources that are not being replaced. We'd better start thinking about it now. We have enough reserves to buy enough time so we will not be threatened as a culture. But we can go blithely on and end up getting to a point where there isn't time to develop systems based on renewable resources.

The shale oil is large too, but it carries a serious environmental problem. The bulk of that 4000 billion/bbls is in an area that is contained in a 30 mile circle. "How valuable is that much land?" How valuable is that much area compared to the welfare of the country? Opinion is divided no matter which way the question is asked. But I ask you to think about it this way. If it takes some number of square miles of surface area to build a solar plant and some number of barrels of oil per square mile for oil shale recovery, how much of each leads to the

most responsible balance in terms of the environment. One of the variables is what you could and will use the land to produce. I would think it a very poor trade to dig up soil which has taken a few tens of thousands of years to develop to produce fuel which will be burned only once. However, if that soil can produce not only food but a little fuel each year it would seem to be better to use it for growing for 10,000 more years. But I wouldn't exclude the thought that 20 square miles is not a very important part of the whole earth surface. It depends on what other things are there, including the viewpoint of the people who live on it.

Most of what follows is redundant in the sense that the same numbers will reappear but presented differently. Figure 4 shows an earlier estimate of world fuel resources and gives you an idea of relative U.S. and World consumption. The U.S. now uses most of the oil produced. While noting this, one should remember that before World War II all of the world's petroleum was produced by the United States. So even though we now import a lot of oil, we produced the whole world supply for forty years.

Figure 5 has a breakdown of the U.S. fossil fuel picture and a footnote with prices. There are two points I want to make from it. One has to do with price and one has to do with fossil resources. When prepared in 1972, the prices in Footnote A were considered extraordinarily high. We estimated that the current FPC gas price at that time was 43 cents/MCF. Intrastate contracts were running around \$1 and per MCF and averaged sales were about 50 cents an MCF. An MCF of gas is 10^6 BTU and that's 1/5 or 1/6 of a barrel. And \$4 a barrel of oil we thought was about the average price of crude oil and 10 mills per kilowatt hour

was a pretty good price for electricity. But if you really let the price increase tremendously the recoverable amounts would be so much bigger that we ought to look at that consequence. The tremendously increased price in 1972, just 4 years ago, was \$1 an MCF for gas, \$6 a barrel for oil, and 12 mills per kilowatt hour average for electricity. At the present, 1976, number 2 fuel oil delivered in industrial quantities in Arizona or New Mexico costs about \$16 a barrel. Not \$6--we missed it by more than a factor of 2 or a factor of 3. The current price of gas is not less than \$1.50 and I recently read of a contract written for future deliveries of \$4 per MCF. So, electrical power will cost 20 mill per kilowatt hour. When you get near the peak of the production curve it costs more in terms of effort and expenditure for every next unit you withdraw. These increasing prices are going to continue until it becomes an economic necessity to conserve. Fuel will be too costly to waste.

Now, in the 1930s the amount that it cost to put gasoline in the car was a significant consideration in deciding if you went someplace or didn't go. Gasoline then was about 14 cents a gallon at the pump plus a nickle tax, so it sold for just under 20 cents.

Finally, Figure 6 shows the U.S. non-fossil and renewable resources.

I could discuss the uranium issue at length. I believe that reserves costing up to \$50 or \$75 a pound are sensible to use in light of the cost of the competing fuels. This was not true five years ago. But when the oil and gas and fossil fuel began to disappear, it became quite clear that \$8 uranium was sort of like 10 cents a barrel oil. We should be thinking in terms of \$50 and above. And that means 100 parts per million uranium ore. Things that we now consider to be non-ore quality

mineral deposits will be ore.

The total geothermal resource is large. It's low quality heat in general but occasionally nature provides us with a hot, near surface deposit. The Salton Sea has enough energy to take care of the western 11 states for the next 2-3 centuries and I'm sure after that we will find other areas. We might even come to the point of viewing Yellowstone Park as not only a wonderful park but as a potential source of enough energy to take care of the western U.S. for the next 1000 years and without damaging the Park.

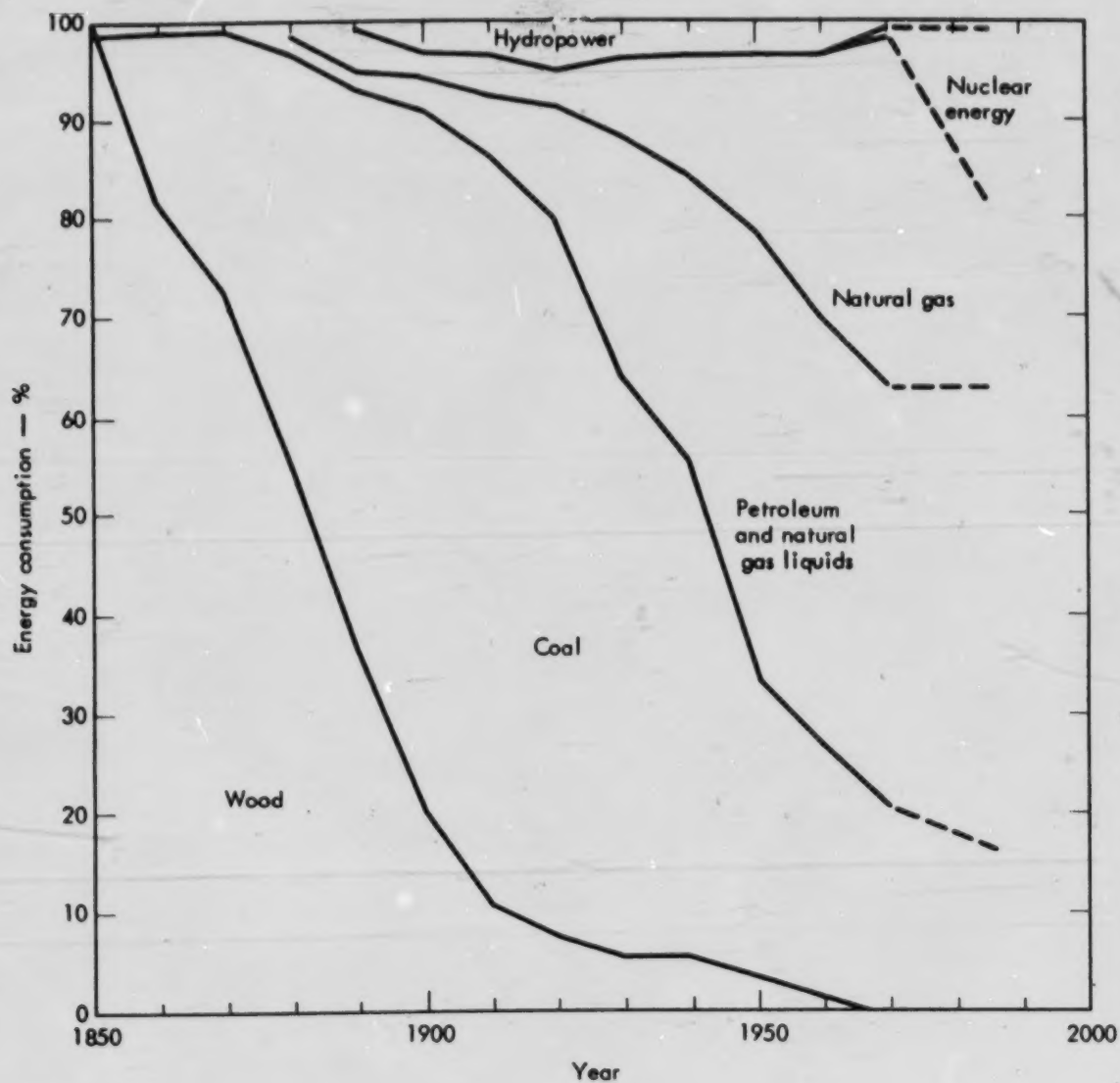
Now the solar energy that we usually think of is just one kind of solar energy. If we use solar energy either for direct electric or thermal electric, that's one way of doing it. It's not always the most useful or efficient and there are serious environmental considerations. The 1000 megawatt plant, 400 square kilometers, is about the size of all the oil shale which contains 1.9×10^{18} BTU. This would generate 1000 MWe for about 50,000 years. It seems the oil shale development is environmentally more responsible. Finally, I would like to add that we have been working recently on solar energy produced by variants of algae which float and so they have the properties of easy harvest. They work around 10% efficiency as solar converters which is about as good as anybody else can do. But what's better about them is they can be made to produce natural gas and liquids.

We have a fossil energy problem. We have enough time to solve that problem but the time is finite. We have to keep the problem before our children and our friends. It is their problem and probably their children's problem. It's also our problem to assure that they do understand it and to guide them toward the limited solutions we can see.

I thank you very much.

FIGURE 1

ENERGY CONTRIBUTIONS FROM PRINCIPAL SOURCES



FROM: E.W. COOK, "FLOW OF ENERGY IN AN INDUSTRIAL SOCIETY" SCIENTIFIC AMERICAN, 9/71

FIGURE 2
WORLD CRUDE OIL PRODUCTION

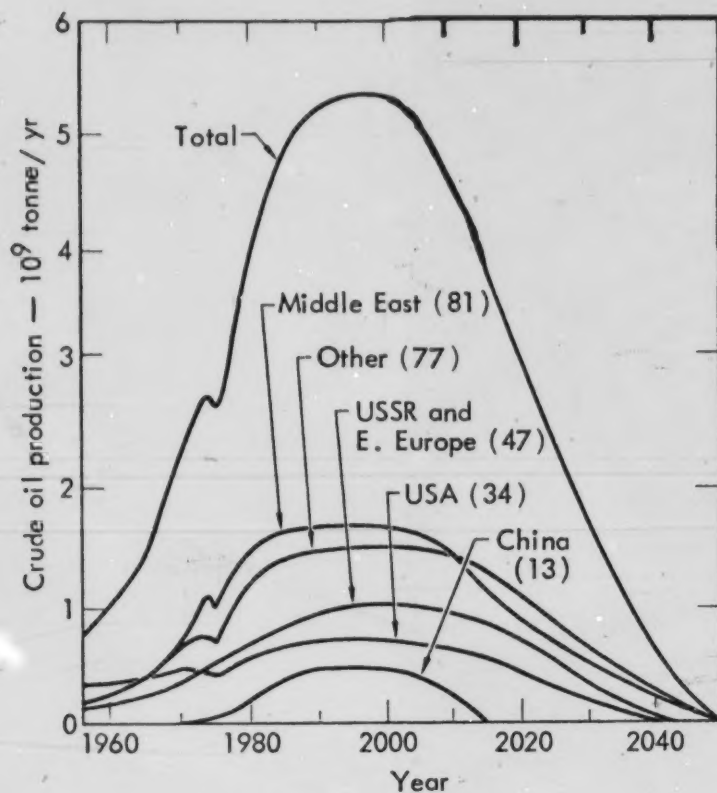


FIGURE 3

U.S. FOSSIL FUEL RESERVES

(UNITS - 10^{18} BTU)

	<u>OIL</u>	<u>GAS</u>	<u>COAL</u>
PROVED	.23	.29	40.5
PROBABLE	.51	.86	8.8
SPECULATIVE	<u>.53</u>	<u>.31</u>	<u>34.1</u>
	1.27	1.46	83.4
<u>OTHER</u>			
HEAVY OIL	.6		
TAR SANDS	.1		
OIL SHALE	<u>12.0</u>		
	<u>12.7</u>		
TOTAL OIL	14.0		

FIGURE 4
WORLD FOSSIL FUEL RESOURCES

<u>REGION</u>	<u>OIL</u>	<u>GAS</u>	<u>COAL</u>	<u>SHALE OIL</u>	<u>TAR SANDS</u>
UNITED STATES	260	260	14,400	4,400	-
FAR EAST	240	190	-	-	-
CANADA	120	90	640	360	450
SOUTH AMERICA	280	210	140	790	-
WESTERN EUROPE	25	35	3,700	20	-
AFRICA	290	240	1,100	100	-
MIDDLE EAST	725	570	-	50	-
PLANNED ECONOMIES	600	480	124,000	100	-

UNITS ARE BILLIONS OF BARRELS OF OIL
OR OIL EQUIVALENT

FIGURE 5

UNITED STATES FOSSIL ENERGY RESOURCES

1970 U.S. energy use = 71×10^{15} Btu

Resource	Present amount of proved recoverable resources at present prices ^a (10 ¹⁵ Btu)	Additional amount recoverable ^b at higher prices ^c (10 ¹⁵ Btu)		Approx. total (10 ¹⁵ Btu)
		Current technology	New technology	
Coal	6,200	—	9,300	15,500
Petroleum and natural gas liquids	250	2,600	290	3,200
Oil shale	—	—	1,900	1,900
Natural gas	280	2,100	500	2,900
Heavy oils and tar sands	n.e.	n.e.	420	420
Total fossil fuels	6,800	4,700	12,400	23,900

^aAbout \$0.50/MCF (gas); \$4.00/bbl (oil); 10 mills/kWh.^bIncludes undiscovered resources.^cUp to \$1.00/MCF (gas); \$6.00/bbl (oil); 12 mills/kWh.

FIGURE 6

UNITED STATES NON-FOSSIL ENERGY RESOURCES

1970 U.S. energy use = 71×10^{15} Btu

Resource	Present amount of proved recoverable resources at present prices ^a (10 ¹⁵ Btu)	Additional amount recoverable ^b at higher prices ^c (10 ¹⁵ Btu)		Approx. total ^d (10 ¹⁵ Btu)
		Current technology	New technology	
Uranium ^a	150	5,700	—	5,900
Thorium	—	—	9,600	9,600
Geothermal	10	7	5,000	500 = 5,000
Solar	Summer, clear day, noon sunshine (southwestern U.S.) = ~0.6 kW/m ² ; a 1000-MW _e power plant might require 400 km ² .			

^aCurrent costs are about \$8/lb U₃O₈, 10 mills/kWh.^bIncreased costs of up to \$50/lb U₃O₈, 13 mills/kWh.^cIncludes undiscovered resources.

ARIZONA'S ENERGY RESOURCES AND DEVELOPMENT

By
DR. WILLIAM H. DRESHER

Dean, College of Mines
Director, Arizona Bureau of Mines
The University of Arizona
Tucson, Arizona 85721

ARIZONA'S ENERGY RESOURCES AND DEVELOPMENT

Before beginning my talk, I would like to announce that I brought some resource material with me. There is a copy for each of you outside--a publication called Field Notes, which is a quarterly publication of the Arizona Bureau of Mines. The Arizona Bureau of Mines is a division of the University of Arizona. It is a separate state agency from the University and its responsibility is to define and report on the mineral resources and geological environment of the State. So if any of you want these, and a good deal of what I'm saying will be contained in these two issues, please pick up a copy. If any of you would like to subscribe to this publication, just send your name and address to me.

Also, I will call your attention to the Proceedings from the latest Arizona Academy activity which was held in Rio Rico last April. On the bulletin board in the hallway, I have put the address of the Academy. The price of the document is \$5.00. You will find it is most interesting, both in regard to the information which it gives you and also the recommendations of the group who attended the Academy.

I want to read the first couple of paragraphs of the Academy book because it sets the scene for what I'm going to talk about today as part of your program.

"There are many serious problems facing mankind. The energy problem may be the most serious for the time scale involved in making significant changes and energy patterns is very long, and the time remaining to effect such changes has nearly expired.

Thus, the challenge facing this 28th Arizona Town Hall has been a uniquely complex and vital one. Ours is not a task of studying a system and recommending improvements aimed at making it work better--we are faced with the formidable task of considering the consequences of converting to a new energy base. For although the present supplies of petroleum are adequate, they are not renewable. Eventually they will be gone. It took man approximately 60 years to convert from wood to coal as his major energy source and another 60 years to convert from coal to a major dependence on oil and natural gas. How we handle the present limited supply of petroleum source fuels and how we make the long run conversion to a new energy base, be it coal, nuclear, oil shale, refuse or geothermal, are questions this Town Hall has dealt with for three days preceded by weeks of individual study by each participant. No subject today is receiving more national attention than that of energy. Each person here knows full well that the national energy crisis is magnified in Arizona. For as Governor Raul Castro reminded us in his keynote address--Arizona is an energy consuming state and not an energy producing state. Therefore, our problem is particularly complex and the solutions even more so. It is, therefore, fitting and timely that this Town Hall should assign top priority to the topic of energy."

One thing I want to make very clear as we look upon a small micro-cosm like Arizona--we can almost relate it to the entire country. Rather than Arizona developing its own Project Independence, I think it's very clear that we must rely on outside sources--just as the United States must rely on outside sources. When our BRDA friends talk about Project Independence, they are not meaning that we should develop 100% of our energy resources within our borders. It means that we should reduce the vulnerability of ourselves to these outside sources. And I think we have to look upon it the same way with Arizona. So while I'm talking, don't get the feeling we should look to home-grown energy sources to supply our complete needs. Let's look upon what we, as a state, can contribute to the entire energy network of our state and our country. So, it's a matter of reducing our dependence from the outside--not necessarily completely replacing it.

I think in discussing our energy dependence we should look upon what our requirements are. Here (Slide 1) is the per capita consumption of energy for a number of our surrounding western states and compared with the entire U.S. You'll notice that for 1972, at least, our consumption was somewhat less than the national average and considerably less than some of the joining states. Our growth rate, however, is extremely large compared to any other area in our region. Therein is the future problem. We are not facing a serious problem yet but we could very well be in the very near future.

The next slide is Arizona's energy consumption by end use (Slide 2). The thing to note here is that our "sore thumb" is the transportation. Naturally, we are few in population numbers and there are very large distances for us to move about. We're low on the industrial side and slightly low on the household and commercial compared to the U.S. Where does it come from? Well, note now (Slide 3)--and study this slide carefully--here we have three years, '65 through '74 arrayed by energy source. If you note the trends--coal is increasing in percentage, hydropower is decreasing in percentage, petroleum is increasing in percentage, and natural gas is decreasing in percentage. Today, hydropower is fairly limited so when we say decreasing in percentage it's because the total consumption is increasing and the amount of hydropower available to us is limited. Coal, naturally must be used in place of natural gas as we must, at least in short run, use petroleum in place of natural gas because it is natural gas that we are really short of. There's enough petroleum available if we want to pay for it, but there's just not enough natural gas under present allowable pricing conditions.

Let's look at some of the same data arrayed in a different manner (Slide 4). Percentage-wise, here's how the uses run for each of the sources. You'll notice that our household and commercial usage is largely natural gas; industrial is largely natural gas; transportation largely petroleum; electricity generation largely coal and hydro. Of course, electricity is not generated for the sake of generating it--it's generated for the sake of using it. In 1974, 64¹/₂% went to the household-commercial sector and 32¹/₂% went to the industrial sector. So then in this way we can say that coal and hydro power are consumed largely by the household, commercial and industrial sectors in our state.

Now, the thing that we are here to hear about. What are the choices which we have? Well, here (Slide 5) are some of them I have noted from a larger list. Naturally, I think we have to eliminate things like tide power from the larger list--we have no oceans. There's some we will eliminate from this list too as we go. But let's talk about them a little bit at a time. I'd like to mention here that there are a number of energy sources on the list which will be covered in more detail by subsequent speakers. So, I'm going to skip over them rather rapidly but I will note when I am doing so. I'm going to go through all of them very rapidly in the beginning and then come back to some of the more important ones.

For those of you who do not know it yet, coal is probably the most abundant naturally occurring fuel energy resource we have in our state. We know of nothing that will beat coal as a fuel energy resource. I say fuel energy because that differentiates from solar energy.

Crop waste, municipal waste, various types of cellulosic materials are another type of material which might be looked upon for fuel energy.

We produce some rather astounding amounts of wastes--110,000 tons per year of sawdust, for example; about 1,500,000 tons a year of agricultural waste; about 1.2 million tons per year of municipal waste and so forth. These materials are potentially useful. There are a number of ways we can convert them--like direct burning, by pyrolysis, by bio-conversion, bio-degradation types of reactions. Some of the problems involved are: the collection of them; the haulage of them--cost in money and cost in energy; the storage of them; and, of course, pollution, the other aspect of the subject. The conversion itself is a pollution problem. In many cases, these materials have a higher value when used for non-energy products. For example, waste paper being recycled into new paper; materials of some of the biochemical conversions can be processed to form cattle feed--a use for the waste which is more commercially viable than its use for energy. So, our energy from waste situation in Arizona is probably fairly limited. We will undoubtedly see some of it on the local scene but the large distances between places in Arizona is going to keep it limited to local use. You can get about 1 kilowatt of electricity per every pound of waste. One rule of thumb is that a 40 ton truck loaded with 40 tons of horse manure can go 40 miles before it burns up the amount of energy contained in the horse manure.

Another area we hear a lot about is geothermal energy. This is energy which comes from the heat stored beneath the surface of the earth. As we'll see a little bit later when I get into the subject in a little more detail, when I say beneath the surface, I'm talking about two miles down. There are two types: there is a vapor-dominated, which is the type in commercial production out of the geysers in California;

and there's the hot water-dominated, which we all like to go and see at Yellowstone. Of the two, the vapor-dominated is the most practical for present day energy conversion. You'll have a speaker later that's going to talk about this in more detail.

Hydroelectric power. About 12% of the total usage in 1974 was hydro-produced. With 51 units producing hydropower in Arizona about 3,000 megawatts total capacity--of those 3,000 megawatts, 875 were available to us in Arizona. In other words, we share those facilities with other states--Nevada, California, Utah. Our hydroelectric production is limited. We have just about run out of sites to build additional dams and in the existing dams, we have run out of water to create more energy. In so far as we know at the present time, the only additional sites available are the Bridge and Marble Canyon sites which, as you know if you followed the news of 5 or 6 years ago, there was a considerable amount of environmental concern over. Contrary to most people's thoughts on these, Bridge and Marble Canyon were peaking power projects. That is, they were not primary power--they were projects in order to store sufficient energy to feed into the system in the peak draw times of the day.

Natural gas. We're going to have more later on this and Mr. Bannister is going to follow me, but I'll just say that we have nil natural gas production in our state. So far we have had insufficient production to warrant even building pipelines to distribute it. Natural gas, of course, is produced with the oil which is produced in the state. The oil can be hauled for further processing but the gas cannot.

Petroleum. The oil side of it will also be covered by Mr. Bannister in the next talk. Oil was discovered in the state about 1954 and the

production to the present time has been about 15 million barrels. Oil produced in the state must be shipped out of the state for refining because we have no refineries in this state.

Sunlight. Sunlight, as we've heard on the news and in most energy-related activities we attend, is the most abundant energy source man has and, of course, we in Arizona have more than most other people. Arizona has the highest mean hours of total sunlight of any state in the nation but that, of course, doesn't mean that we have a monopoly on it. Solar energy conversion can be practiced in any state. It's just a matter of where you have enough of it to make it economical. We know now how to utilize solar energy and I'm sure you must realize that. If you've traveled in foreign countries (and I was in Israel a year ago this time) you would see that the roofs of the buildings are a forest of hot water heaters which are solar heated. It can be done if you are willing to pay the capital cost of the equipment. Of course the operating cost is nil but the capital cost is ten times the cost of a domestic hot water heater now. Space heating and cooling--we know there are a number of demonstration units throughout the country which have been built to heat and cool buildings. More and more of them, of course, are being built--the equipment required are items of commerce--you can buy them today. It's not a matter of technology, it's just a matter of doing it. The area where we do need new technology is in how to convert sunlight into electricity of sufficient power level that we can carry it over the power lines of the utilities. That is the form which is most easily adapted to our present system but that is the part we cannot now do. That is the type of activity a solar energy research center would be aiming its major thrust toward. I'm sure Mr. Halacy tomorrow is going

to be talking about that part of the solar energy problem in great detail.

Uranium, of course, refers to nuclear power. Again, like our other energy-source precautions, let me warn you that even uranium which does occur and we have mined in our state must be shipped out of state for processing and then shipped back for a conversion into energy. We have no uranium processing mills or plants in our state. When the Palo Verde plant is built, we will have the capability of converting uranium, enriched uranium, into electrical energy. At the present time, we do not have that capability. There has been about 350 tons of U_3O_8 mined in the state. We do have a small amount of reserves--most of these reserves are on the Navajo Indian Reservation. The uranium must be shipped out and one of the things which has held back development of any other uranium resources in our state is that there is not enough available to warrant building a uranium processing plant. There is a considerable amount of activity currently going on in the state. My agents in the Arizona Bureau of Mines are doing some work, Exxon Company is doing exploration, the United States Geological Survey is doing exploration, and the ERDA people from Grand Junction, Colorado, are exploring in this state.

I want to mention to any of you who can visualize or remember that there is a uranium mine very close to Bright Angel Lodge in the Grand Canyon. To me, it's a living example of mining in a national park because very few visitors even notice it. It's called the Orphan Mine. It's not presently operating but it will be starting up shortly, I'm sure, if our uranium needs become sufficient to warrant it. It's owned by the Cotter Corporation of Colorado.

Wind power, last on my list. It's probably the least practical solution for Arizona and in irony, the windiest spot in the state is called Winslow (Wind-s-low"). In Winslow, Arizona, the average wind velocity is 8.3 miles per hour and gusts occur up to 68 miles per hour. The highest average wind velocity is about 12 miles per hour at dusk. When we compare these numbers with the performance numbers of any wind generating equipment that we know of today, it just won't hold up. As an example, NASA is building one in Cleveland, Ohio, called the Plum Brook Machine that will have blades on it 125 feet in diameter. It will rest on a tower 100 feet high. It will generate about 100 kilowatts--that's enough electricity for 1,000 100-watt light bulbs! It will provide enough power for about 30 average size homes. Now, if we were to take the performance characteristics of that machine and just make one minor correction. Say, instead of operating at about 40% efficiency, as it is designed to operate, let it operate at 100% efficiency. This, incidentally, says that any wind going into the blades comes out at zero velocity. Then, under these conditions it would take 692 units to provide the household power for Winslow. That would be a Chinese wall of windmills around the city! So let's rest right there. Our farms can use it--we've seen them around the state--they have capabilities of pumping water in gusty periods and storing it for cattle, but don't count on it to power your households.

Now, let's look in some amount of detail at Arizona's mineral fuel sources. First of all, let's look at the geology of Arizona. As you'll see as I talk, our sources are very much dependent upon the rocks that Nature gave us in Arizona. We are basically divided into two geologic provinces (Slide 6). We have the Basin and Range Province where Phoenix

and Tucson lie (and actually 90% of the population lives) and then we have the Plateau Province. The Plateau Province consists of the youngest rocks. They are fairly well intact. There's been some erosion in the Plateau Province--the Grand Canyon, for example. I think it's interesting to note (and we're going to have a lot to say about it in a moment) that the Black Mesa is sort of a remnant of the surface that once was. We have, preserved in Black Mesa, geologic era in 5 different strata. For the rest of the Plateau Province a good deal of that strata eroded away and went flowing down the Grand Canyon. So who knows how much coal and oil and gas has escaped us down the Grand Canyon. Now, you might say--why aren't these things found in the Basin and Range Province? The Basin and the Range Province is something entirely different for it has been ripped asunder by many geologic episodes. The rocks have fractured, they are fragmentized, they have been turned over, rubblized and it's a small wonder that anything remains. However, we also note that our major metallic mineral resources occur in the Basin and Range Province because this rock fracturing has made it ideal for secondary enrichment of metal-liferous ores to come in and lodge themselves as a mineral deposit. So, our older mineral resources, the fuel resources, can be found intact in the Plateau Province but not in the Basin and Range Province. This is the reason we find our coal, oil and gas and uranium in the north and northeastern part of the state and not in the south and southwestern part of the state.

This is a satellite photograph of the northeastern part of the state (Slide 7). We've blocked out on it a number of the points of interest--Black Mesa being in the middle showing the Navajo, the Hopi and the joint use lands and up there in the northeastern part of the state and on up

into Utah and over into New Mexico some of the oil and gas operations. Let's talk about this a little bit.

Black Mesa represents 3200 square miles, about 3% of Arizona's land area. It's larger than the State of Delaware, it's 100% Indian owned. Arizona's coal resources are located in, on and under Black Mesa. There's very little coal of commercial value anywhere else in the state. The coal company which is now in operation, Peabody Coal Company, is processing under contract with two power plants--the Navajo power plant and the Mohave power plant. Dresser Industries is proposing an operation and we'll mention a little bit more about the growth of those as we go along. Peabody Coal has a unit train which runs from the mine to the Navajo power plant at Page and a slurry pipeline which runs from the mine to the Mohave power plant in Nevada.

Oil and gas resources are located in the northeastern part of the state and I have indicated in the slide the location of a number of the wells. I'm sure Mr. Bannister will go into quite a bit of detail on those so I won't go much further on the subject. The first discovery of oil in Arizona was in 1954 and it was by Shell Oil Company up in the northeast corner of the state. Shortly after that, in 1956, the very large field labeled "1" on this slide was found in Utah.

Let's look at Black Mesa coals in some amount of detail. Slide 9 is a breakdown of coals and their classification. It's rather confusing to most people what makes coal valuable. Anthracite has the highest carbon content and the lowest amount of volatile matter and ash. That's the type of coal you find in Pennsylvania. Of course, the best grades of coal are commercially termed "metallurgical" grades and used for the production of steel rather than for heating value. Bituminous coal is

what we mostly use for heating and the Black Mesa material is somewhere between bituminous and sub-bituminous in heating value, ash content and so forth. Lignins are the type of coals we find in the Dakotas, low grade materials--a lot of volatiles, a lot of smelly stuff comes off when they are burned. Black Mesa coal is a pretty good grade of coal. The details are shown in Slide 9.

There are three seams of coal in Black Mesa. A coal seam is a well defined thickness of coal that can be mined out. If it is surface mined, it can be nearly 100% removed. If it's underground mined then you have to leave some to prop up the ground above it. Black Mesa, of course, is surface mined and their seam is about 12 feet thick. There are three seams: Dakota coal, Toreva coal, and Wepo coal. Actually, as I mentioned earlier, Black Mesa has five different layers. There's the Yale Point Sandstone; next is the Wepo Formation (the distance from the surface to the bottom of the Wepo formation is 130 feet); the Toreva Formation which is next contains coal; the Mancos Shale and then the Dakota Sandstone. The Dakota Formation contains coal and that distance from the surface is 1700 feet. So far the only coal mined is from the 130 foot level material from the Wepo and some of the Toreva formation.

The estimated gross resources--now watch in my talk. I'll use the word "resource" and I'll use the word "reserve" and I'm going to explain that in just a moment. But for now, the resources are estimated at 21 billion tons. The details are shown in Slide 10. Now, this necessarily has to be an estimate for reasons I'll tell you in a moment. Again, by the formations, the Wepo is being mined from the surface and by the Toreva and the Dakota being mined, we're talking about mining along the periphery of the Mesa, not the heart of the Mesa. In other words, these are acces-

sible from the sides. Over hundreds of years the Indians have operated little "Mom and Pop" mines to keep themselves warm from these strata.

If we consider all the material which is hypothetically available, we call them a "resource"; that's the total block that is shown in Slide 11. So, when I said 21 billion tons, I was talking of the estimate of the total block. Now, as we learn more about the resource, either geologically (in the horizontal direction) or economically (in the vertical direction), we move to another block called "reserves." The "reserves" are a smaller number than the "resource" but like a bird in the hand, we know what they are. We know we can mine reserves at a particular cost and provide the coal for a particular price. The Black Mesa reserves are about 400 million tons. Now look at those two numbers-- 21 billion and 400 million. The only thing we know about the reserves is what Peabody Coal says is under their lease area and I pointed out to you earlier what a small portion that lease area is. So I think it's pretty obvious that the amount of coal on Black Mesa is far more than has been officially recorded. Peabody Coal lease consists of seven tenths of the entire mesa--it's 14,000 acres under lease. They'll be producing from 400 acres a year for 35 years to feed the two power plants. Therefore, that calculates out to their 400 million tons in reserves or about 11 million tons mined per year. While all of the energy derived from this coal does not come to Arizona let's look at the significance as if it did. Arizona consumed, in 1972, an amount of energy equivalent to 21 million tons of coal. We saw earlier that it wasn't just coal-- it was petroleum, hydro-power, and a lot of things. The equivalent energy would be 21 million tons of coal--that's about twice what Black Mesa has produced in that year. That is equivalent to about 94 million

barrels of crude oil. The 16 million tons of coal under each square mile of the Peabody lease would be equivalent to 71 million barrels of oil. In other words, there are about 40 days total U.S. petroleum requirement under every square mile of Black Mesa (at least from the data we know from the Peabody lease). So I think you will agree that we have a rather significant energy source within the borders of Arizona.

As I mentioned earlier, oil was discovered about 1954 and we began production in 1966. As Slide 12 shows, it peaked out about 1969 and it's been on the decline ever since. I'll let John Bannister explain that one in the next talk. I want to say, however, I don't feel any of us should be pessimistic about a curve like this. When you know the vagaries of geology you must realize that we just don't know enough information to know the full story. You saw earlier on the satellite photograph a very large oil field up there in Utah and really, it's just a few miles from the Arizona border. They produced about 250 million barrels of oil in the time we produced our 15 million barrels of oil. Now, what was it that was different about the rocks that gave Utah all that oil and hasn't given Arizona oil? Well, there are differences but we don't really know enough yet to say what they are or how important they are. So, our oil and gas reserves are still a big question mark. We just don't know enough.

One of the things with regard to any mineral resource is, as I mentioned earlier, we need more information--geologic information, technologic information, and economic information. I think this holds true for our oil and gas in particular. We need a lot more geological study, first of all, to learn more about the nature of the occurrence of oil and

eventually, we're going to need some technological interpretation applied to this information before we can say we have a reserve. That's true with copper, aluminum or any mineral resource. This is an example of where technology fits in. Technology converts a "resource" to a "reserve"--something which is rather nebulous to something which is a bird in the hand.

Now let's shift over to geothermal energy. Again, as I said, you're going to have a speaker later on talking in some detail about this energy source but let's look at it from Arizona's point of view. There have been a number of holes drilled in the state in past years, there are a number of hot springs in the state, and I have drawn some of the locations on this map (Slide 13). Let's talk a little bit about them. First of all, we generally think in terms of geothermal resource in three classes. The first class is that which can be used for electric power generation. That requires at least 150°C (that's 300°F). Second class, 90°C - 150°C (that's 190°F - 300°F); this class can be used for space heating and process heating. And the last one, is less than 90°C , less than boiling of water; this class is of very little use. So far as Arizona is concerned, we have, as far as we know, two areas with class 1. One is the number 1 point at Power Ranch just south of Phoenix. (Incidentally, that measurement was 180°C and it was a hole 2 miles deep.) Tucson does not like to be out-done by Phoenix so the other one is here, just south of Tucson. This is the Exxon hole which is 12,556 feet deep and slightly lower in temperature than the Phoenix one; it was 146°C . Most of the dots on the map are areas where there were springs or 10,000 foot deep wells which were class 2. All the points in Apache County (along the northeast) were class 3 and these measurements came from holes 3500 to 8500 feet deep.

Now, what do we mean by geothermal? Well, let's look at two cases. Slide 14 is the hypothetical case for the basin and range province-- that city in the slide could be Tucson or Phoenix--we're looking for the closeness to the surface of potentially hot rocks. It's these rocks that provide the heat and we're looking for very high fluxes of heat at depth. So, once we have the heat, it is possible either to inject water or utilize local water to make hot water or steam. A lot depends then on the presence of the hot rocks and the piping system to get the water to the rocks. The piping system may be the sand and gravel of the valley fill; it may be rock systems or fractures. There are a number of things to consider. Slide 15 shows a similar design for the Plateau region of the state. This situation would be more the traditional volcanic type of arrangement where, perhaps, we can come a little bit closer to the surface because of some of the volcanic pipes which are there. Again we depend on porous zones of sandstone and other porous rock structures to get the water into the hot spots. One proposal that Los Alamos National Laboratory is working on is the "hot rock" philosophy of actually drilling into the heated area and pumping water down and removing hot water or preferably steam.

There are a lot of problems yet to be solved for geothermal energy. Finding the most optimal spots in the earth to drill is just one of the problems. The type of system used is going to have a lot to do with how it is ultimately used. For example, the waters which come out of these are quite saline; they are very difficult to handle in heat exchange systems. The geysers area was closed down a few months ago because of the escape of hydrogen sulfide gas and its spread over the whole area. There are great problems with geothermal energy. It is

not necessarily a clean source of energy; there are a lot of brines and gases to get rid of some way or another.

Let's look also at two situations now in Arizona which are not energy producers per se, can help us solve some of our energy problems. This is the story of energy storage. There are 22 places in Arizona which have been defined by the Federal Power Commission just in the last year as being potential "pumped storage" sites. What we mean by "pumped storage" is that during the day, or late at night, when our energy usage is low, we run a pump and pump water uphill into a reservoir. Late in the afternoon, or early in the evening, when our energy consumption is high, we allow the water to run back down and run the pump in reverse so that the pump becomes a generator and, in effect, flow the energy back into our system again. These 22 sites, if at all implemented, would be about the equivalent of 37,000 megawatts of energy. Now, you've got to remember that's not new energy; it's just a way of storing energy to use it when you need it--tonight, next week, whenever you want to. You'd have to put the energy into the system to pump the water up in the first place.

The other potential for Arizona is the storage of gas in some of our salt deposits. There are three places in the state. This particular one I've used as an example (Slide 16) is the Red Lake deposit in the northwest quadrant of the state. We're talking about 8,000 feet of solid rock salt. This is the area where El Paso Natural Gas had proposed a few years ago setting off a nuclear blast to create a cavity to store natural gas in. Now, quietly and unbeknownst to a lot of people, gas is being stored in two other deposits. One of them is right outside Phoenix near Luke Air Force Base. At this location, Calgas operates a propane

distribution center. In that case, the salt has been dissolved by pumping water down, bringing brine out, solar evaporating the brine, selling the salt to the cattle growers, and then renting the hole in the ground to Calgas. The other place is near Holbrook where the Santa Fe Railroad has a butane storage place. So, this is practical; it is going on today, and it is another example of what we can do in this state to help ourselves. At least we can store some energy for our own use.

I don't think any discussion of energy in Arizona should be complete without talking a little bit on the constraints to energy resource development. First and foremost, I think you should note that most of our fossil energy is on Indian lands, i.e., federally-controlled lands. The red tape this creates is unbelievable. I spent a whole morning with the chief geologist of Dresser Industries a week ago. They are dead in the water--not because the Indians won't sign the contract (they already have), but because the Federal Government is making them fill out so many forms it's taking forever to get them processed. So it's not a matter of technology or anything else, it's a matter of just getting through the obstacle course that we have set up for ourselves. The number of environmental impact statements and the number of regulatory aspects of the problem have really shackled us in any kind of mineral resource development. Another problem is water availability. No amount of fossil energy can be generated without water. Water, of course, is a serious constraint in our state.

Technology, too, is a problem. When we talk about solar, geothermal, or even coal gasification, technology is a limiting factor. You must realize that in Arizona or almost anywhere else in the nation our prime

energy transport system is pipelines. Somehow, we have to get coal gasified, coal liquified in order to use it in those pipelines. So, technology is an important point.

The availability of capital is yet another problem. We are fast running out of the availability to generate the sums of moneys which are required. The Kaiparowits Plant in southern Utah--the companies backed off because the sum of money was too great. The coal gasification plant at Shiprock, New Mexico, which El Paso proposed--the company backed off because it became too expensive. No one could have afforded the gas they would have produced. This is a very serious constraint.

So, in conclusion, I think we must say that Arizona must continue to look beyond its borders for energy supplies, but it behooves us to derive as much as possible from our own native sources. We have the ability to do so beyond our present means--it's most important that we develop the information, the geologic information, and the technologic information necessary to do so.

PER CAPITA ENERGY CONSUMPTION

	1972 Per Capita Consumption (Million BTUs)	1957-1971 Growth (%/Yr.)
Arizona	301	5.9
California	252	4.0
Colorado	323	3.5
Nevada	500	8.2
New Mexico	571	4.8
Utah	364	2.8
Total U. S.	346	3.6

SLIDE 1

ARIZONA AND U. S. ENERGY CONSUMPTION BY END USE - 1974

User Class	Per Cent	
	Arizona	U. S.
Household/ Commercial	27.9	29.2
Industrial	28.6	39.9
Transportation	41.8	30.6
Electricity Generation	(Included in Household/Commercial and in Industrial)	
Miscellaneous	1.7	0.3
Total	100.0	100.0

SLIDE 2

ARIZONA GROSS ENERGY INPUTS BY SOURCES
1965 - 1974

(Trillion BTUs and Per Cent)

	1974		1971		1965	
Coal*	75.8	11.7%	46.2	8.7%	21.8	6.0%
Natural Gas	196.5	30.4	219.9	41.2	161.6	45.0
Petroleum	297.3	46.0	198.6	37.2	129.3	36.0
Hydropower	76.8	11.9	68.7	12.9	46.7	13.0
Total	646.4	100.0	533.5	100.0	359.4	100.0

*Includes coal burned in Arizona plus coal-equivalent of electricity imported into the State.

SLIDE 3

ARIZONA GROSS ENERGY INPUTS - 1974
SUPPLY SOURCES BY USER CLASS

Per Cent

User Class	Natural Gas	Petroleum	Coal	Hydropower
Household/ Commercial	32.7	3.2	*	—
Industrial	33.7	14.3	*	—
Transportation	11.6	62.0	—	—
Electricity** Generation	20.9	18.5	99.6	100.0
Miscellaneous	1.1	2.0	0.4	—
Total	100.0	100.0	100.0	100.0

*Included in miscellaneous

**Electricity was distributed approx. 64.5% to Household/Commercial
32.5% to Industrial

SLIDE 4

ARIZONA'S ENERGY RESOURCES

Coal	Oil
Crop Wastes	Sunlight
Geothermal	Urban Wastes
Hydroelectric	Uranium
Natural Gas	Windpower

SLIDE 5

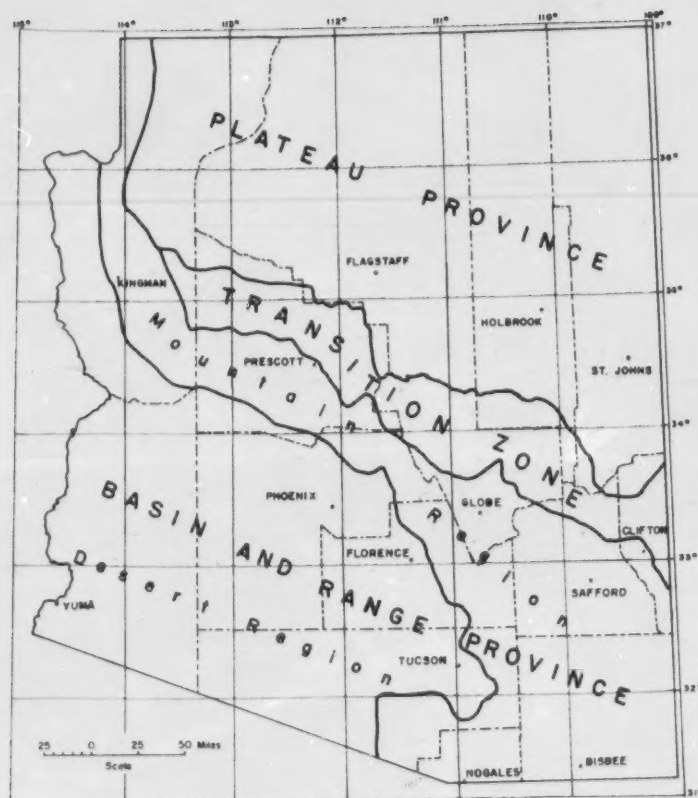


Fig. 13. Physiographic provinces in Arizona.

SLIDE 6

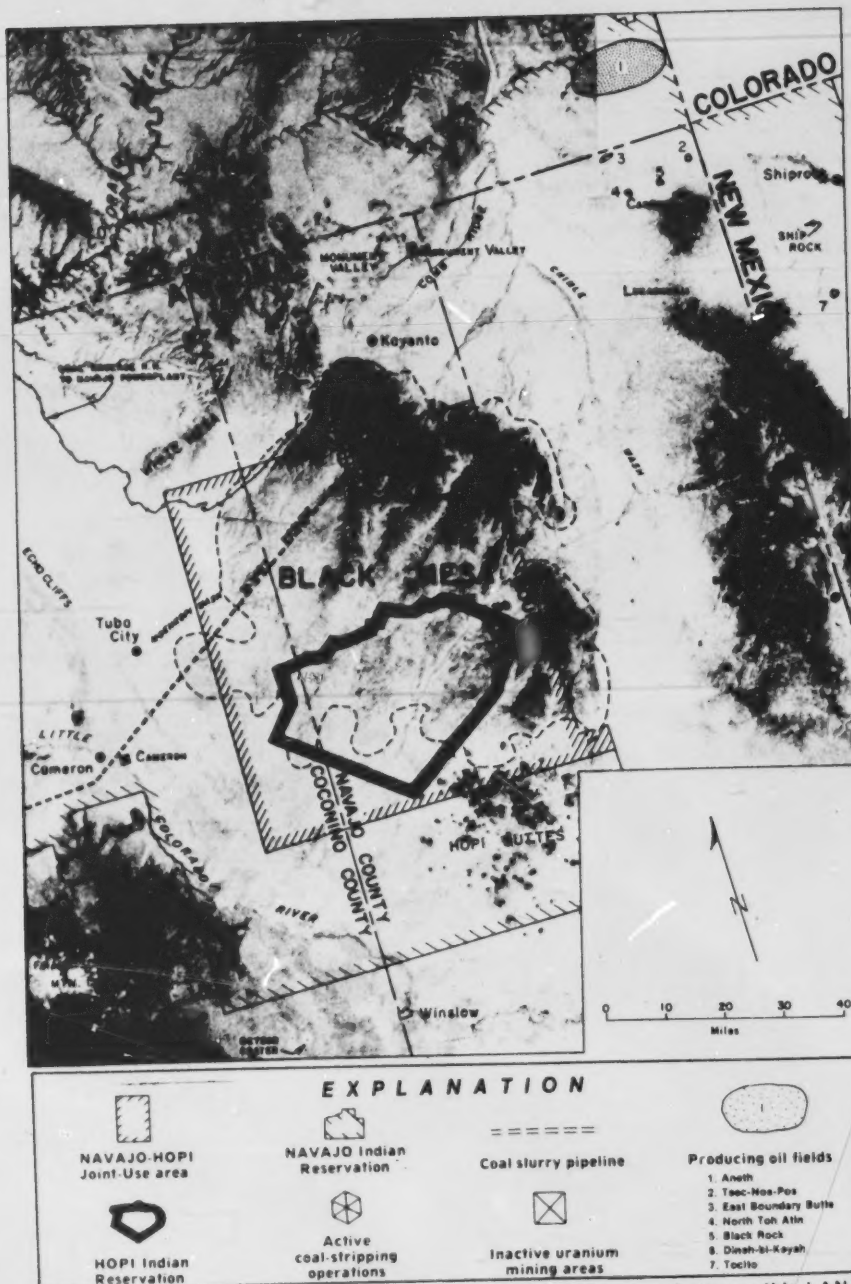


Figure 1. 20,000 square miles of Arizona and adjoining states are shown on this LANDSAT imagery.

SLIDE 7

CLASSIFICATION OF COALS BY RANK

Class	Fixed Carbon Limits Percent	Volatile Matter Limits Percent	Energy Content Limits BTU/lb.
I. Anthracite	86 - 98	< 2 - 14	---
II. Bituminous	69 - 86	14 - 31	10,500-14,000
III. Subbituminous	---	---	8,300-11,500
IV. Lignitic	---	---	6,300- 8,300

SLIDE 8

QUALITY AND HEAT CONTENT OF BLACK MESA COALS

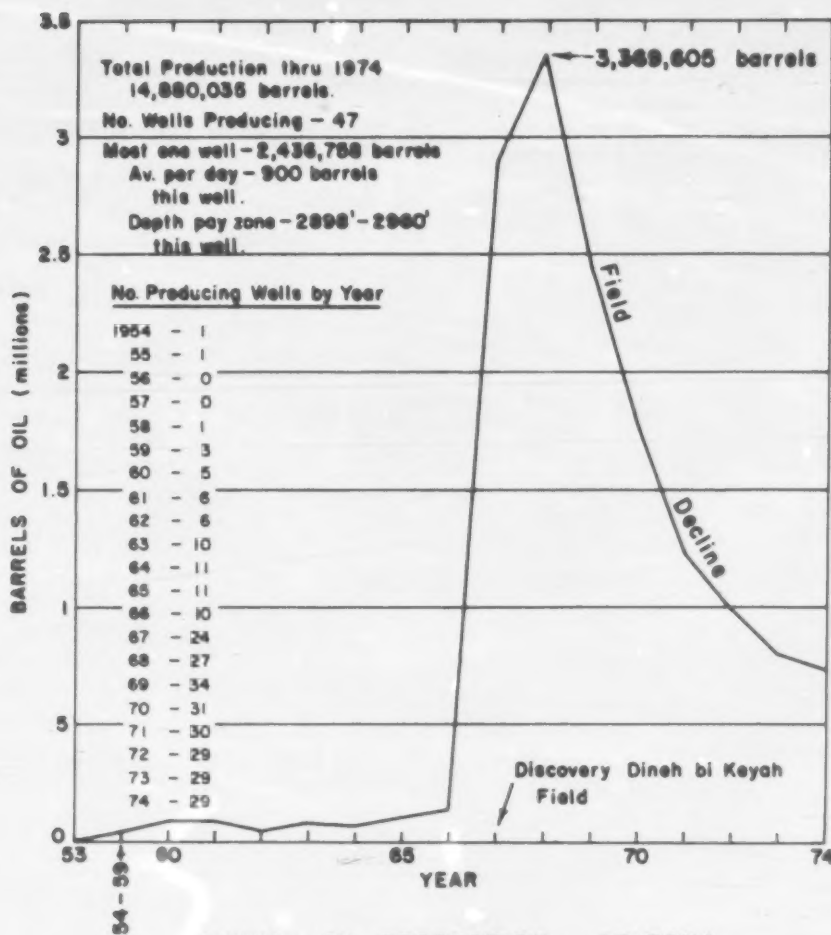
	<u>Dakota Coal</u>	<u>Toreva Coal</u>	<u>Wepo Coal</u>
Av. Ash (%)	11.9	13.8	5.20
Av. Sulfur (%)	1.62	1.09	0.58
Av. BTU/lb.	11,125.00	12,338.00	12,382.00

SLIDE 9

ESTIMATED GROSS COAL RESOURCES OF BLACK MESA

	<u>Billions of Short Tons</u>	<u>Utilization</u>
Wepo Formation	5.65	Presently being mined
Toreva Formation	6.00	Small mines - inoperative
Dakota Sandstone	9.60	Small mines - inoperative
Total	21.25	

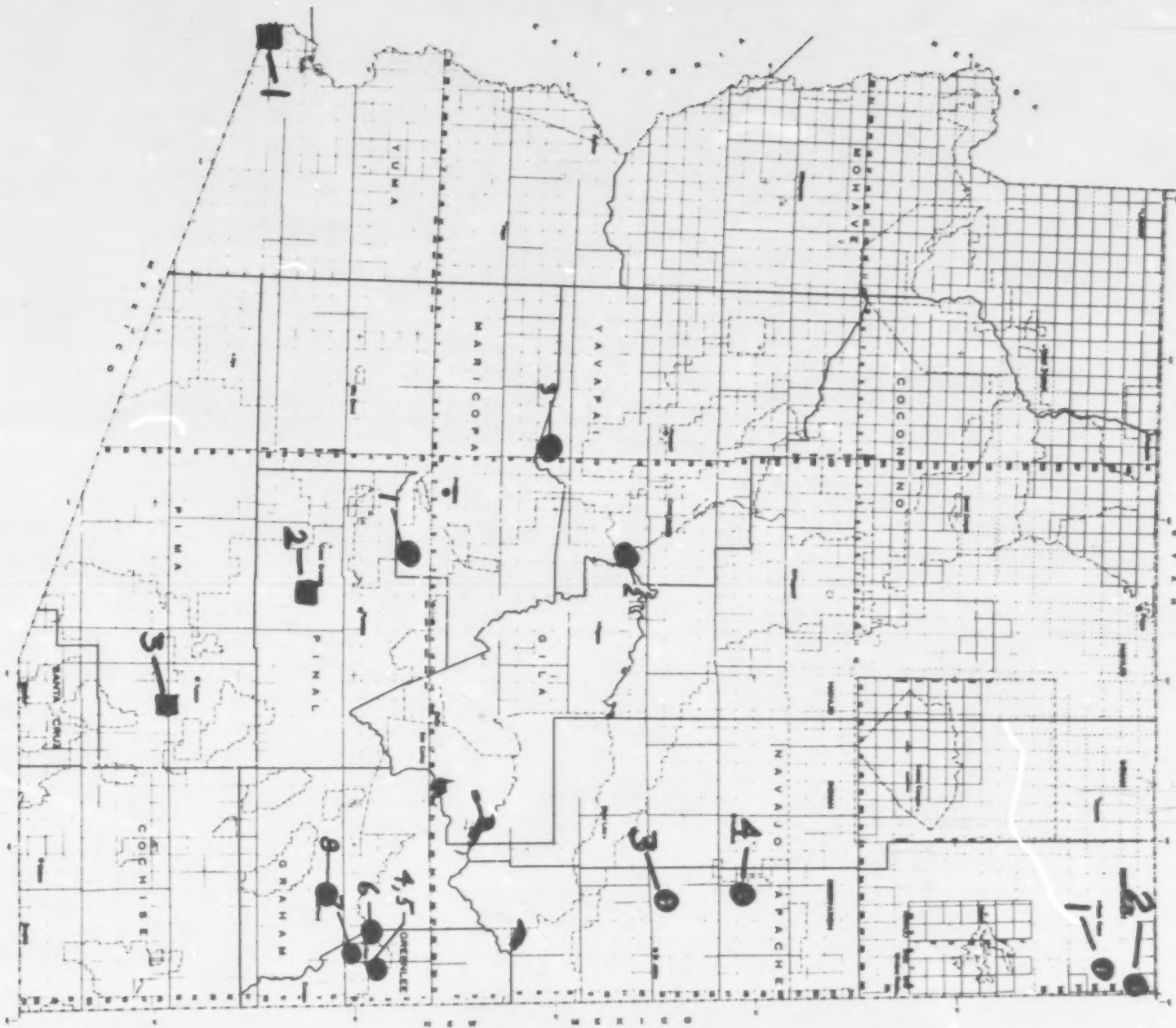
SLIDE 10



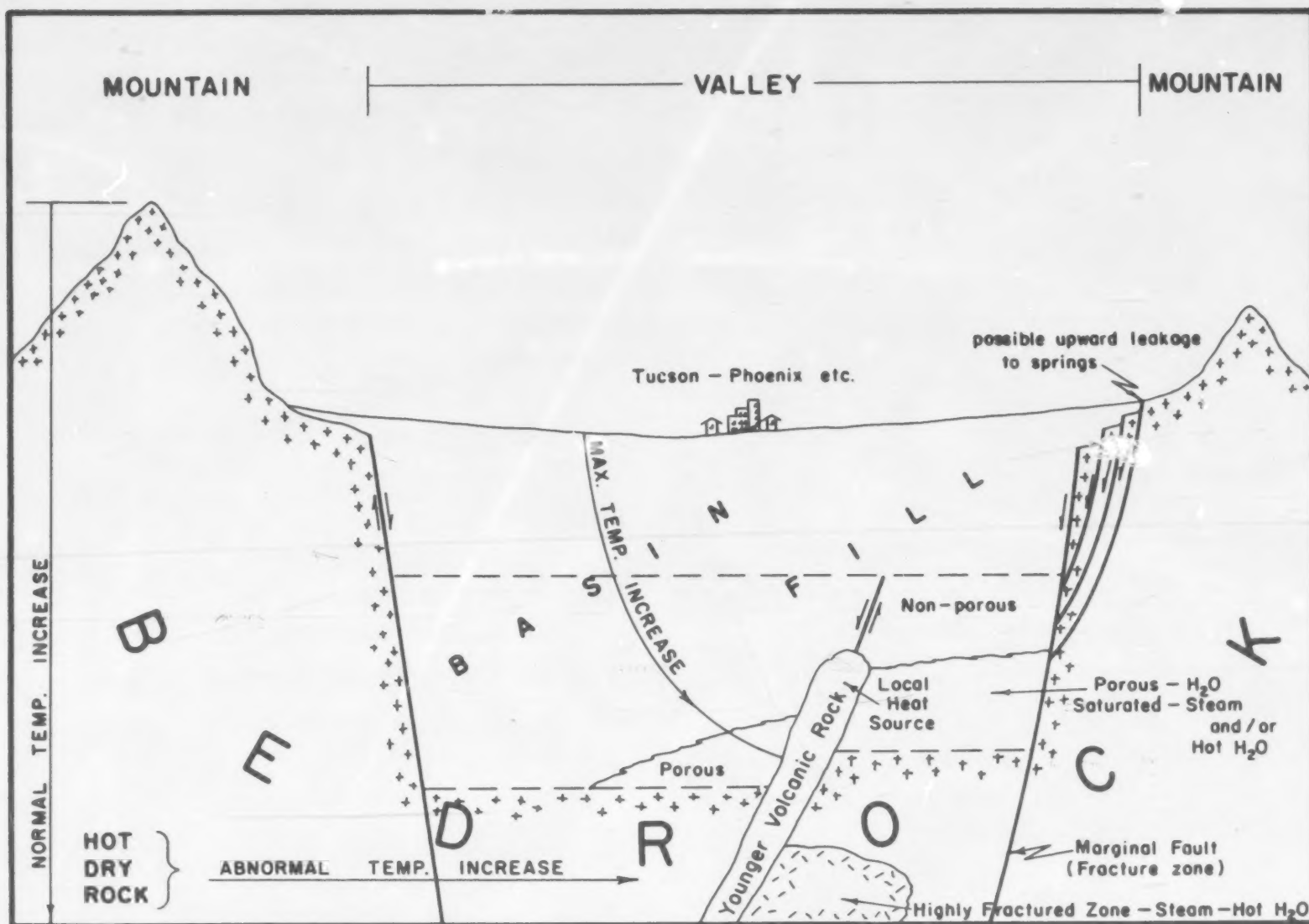
ANNUAL OIL PRODUCTION - ARIZONA 1954 - 1974

(Data from Arizona Oil & Gas Conservation Commission)

SLIDE 12

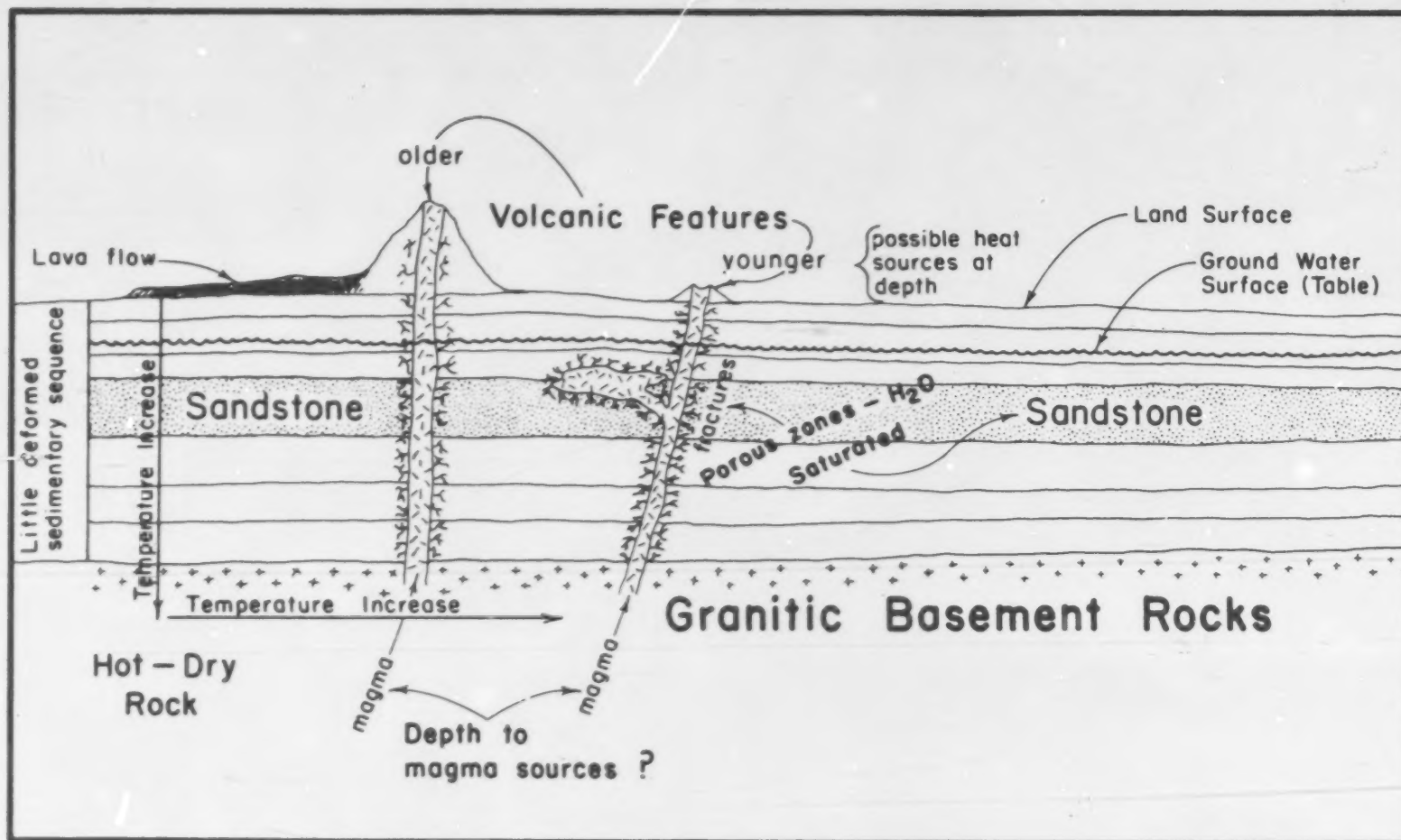


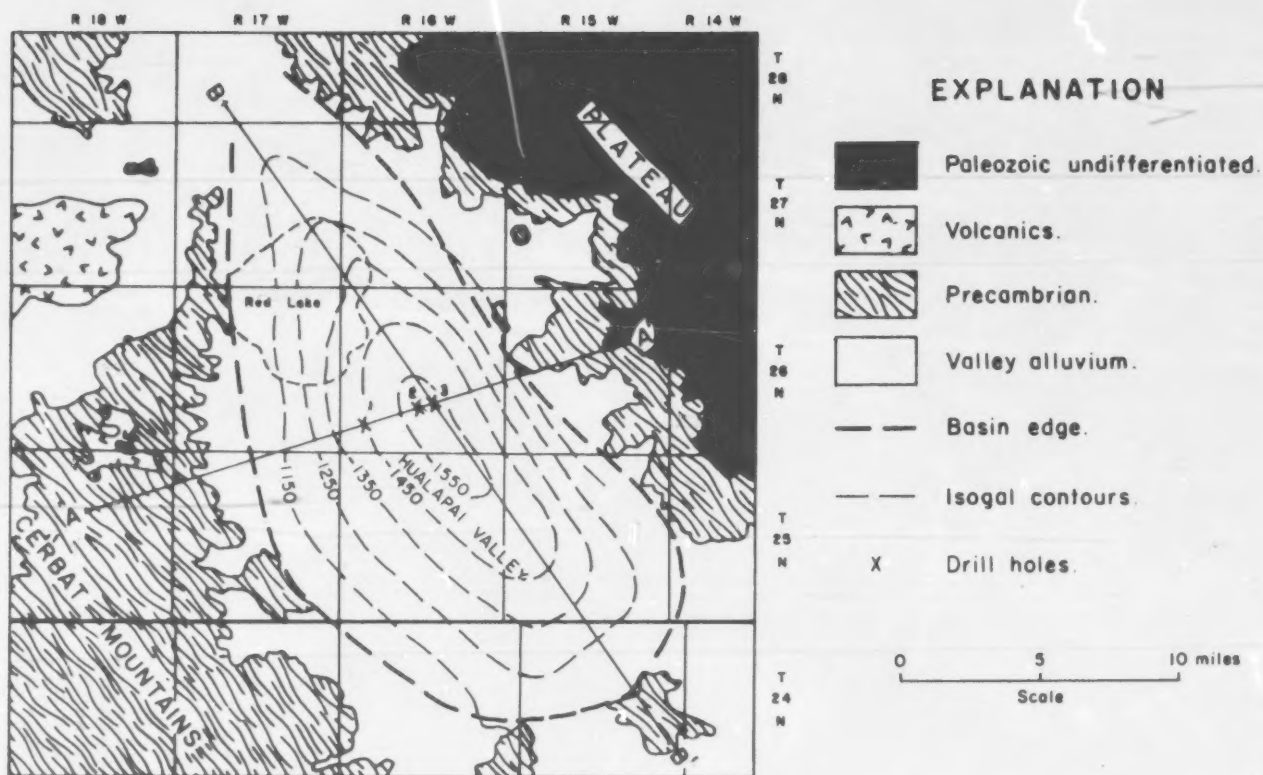
SLIDE 13



SLIDE 14

Possible Geothermal Energy Sources in the Basin and Range Province of Southern Arizona.





SLIDE 16

General Geologic Map of the Red Lake-Hualapai Valley Area
in Mohave County.

COAL TECHNOLOGY - MINING AND ENERGY CONVERSION IN THE U.S.A.

By
C. R. DRAPER

**Administrator
Research and Information Systems Division
Department of Intergovernmental Relations
Capitol Post Office
Helena, Montana 59610**

COAL TECHNOLOGY - MINING AND ENERGY
CONVERSION IN THE U.S.A.

I. Fossil Fuels and the Future

One way to put the supply and utilization of our fossil fuels into historical perspective is to make some assumptions about the life of our solar system, and then reduce the billions of years to something more understandable. I'm assuming the life of our earth and its system-- from Creation to that final, inevitable disaster when the Sun either burns out or flares into a Nova -- is on the order of 10 billion years, of which we have already used up the first 5 billion or so. Now whether or not you accept that estimate depends on who your favorite geomorphologist is, or perhaps how you read and interpret the creation story in the Hebrew Bible.

But humor me for the moment, and accept my guesstimate. Now let's collapse that vast span of time to one single year. The earth was created 6 months ago -- around last Christmas time -- here it is June, and we have until next December to go. It has been $1\frac{1}{2}$ seconds since Columbus discovered this continent, and the Declaration of Independence was signed 0.63 seconds ago. Next, let's assume that mankind has been working on using up his fossil fuel supply for a thousand years. (That's a pretty generous assumption you realize; he wasn't making much of a dent in the supply 1000 years ago). But on our compressed time-scale this means we have been burning up the coal, oil, and natural gas at an accelerating rate for the past 3.15 seconds. At this rate, of course,

we'll be finished with the fossil fuels in about the time it takes to blink your eyes.

But now let's say that mankind decides to mount a crash program immediately to stretch out the remaining supply by superhuman efforts at conservation -- and that by some incredible combination of scaling down and self-denial and substitution, he manages to make the supply last 10 times as long as it would otherwise. Now back to our time scale. This would still mean that all fossil fuels would be used up long before the minute we are in now is finished.

Obviously, conservation -- even extreme conservation -- is not going to be the answer to our energy problems and those of our descendents. But don't let me leave you with the idea that conservation is futile. It just may be, in fact, that only through conservation of this resource will we get the chance to keep alive the technology that we must depend on to invent ways to use the next source of energy, and do so before the lights flicker out. It's going to get mighty cold, you know, between now and next December.

II. In the Meantime - Coal

In the meantime, however, there are decisions to be made as to what to do with the remaining fuel resources, and my assignment has to do with coal. Here in the U.S.A. they tell us we have something like a fifth of the world supply -- which is only mildly interesting, since the prospects are fairly dim for much intercontinental shifting around of coal. The U.S. Geological Survey uses numbers like 3 trillion tons or more left in the ground and the map (Illustration #1) shows approximately how the supply is distributed throughout the country and its "coal provinces." What it does not show is where those supplies occur

with respect to the surface, nor how much lies under each of those blobs on the map.

Actually, about 45% of all this coal and lignite lies under the land in the Northern Great Plains province, and another 18% is in the Rocky Mountain province where we are now -- for a total of about two thousand billion tons. In what is called the Fort Union formation up in our Northern Great Plains province, we have something like a corner on all the lignite, which as you can see from this chart (Illustration #2) of the rankings according to energy content, rates lowest in British Thermal Units per pound or per ton.

But the question "how much coal do we have left" is actually no more simple to answer than is the same question for any other resource you have to dig or pump out of the ground. It depends a lot on who is making the estimate; and there are a lot of people who will dispute the U.S.G.S. estimates. In a very important sense, though, the question of who is right and who's wrong is beside the point. The fact is that we will never get out all the coal there is, any more than we'll get all the oil or natural gas or aluminum or gold or any other natural resource, because we can't afford to. What's really important is the question "how much is there that we can, or will ever be able to use?" You see, over 90 percent of that 3 trillion tons is in the category called "submarginal" -- too deep and/or occurring in beds that are too thin to mine by present technology, at a price that would pay anyone in his right mind to dig it out. Over half of it, incidentally, is assumed to be down there somewhere, although it hasn't as yet been discovered.

Nevertheless, there is still a lot of coal. Here in the West, most of it is owned or controlled by the Federal government. In Montana alone,

there are some 25 million acres underlain by federal coal, and the Department of Interior right now has under lease enough of this acreage to produce almost 2 billion tons.

The question of whose coal it actually is, by the way, represents another interesting problem. In a more or less democratic society with a more or less capitalistic economy, this isn't always exactly clear. At high-level conferences in Washington, of course all that 3 trillion tons is referred to as "our" coal. But in pronouncements by each state governor, the share underlying the land within his state's boundaries is confidently called "our coal". Federal policymakers and state governors, however, dig and sell very little coal as a rule. When you talk to the men whose companies leased the coal lands or bought them; struggled with state and federal regulations; bargained on royalties; signed contracts; and fought the battles of priorities, outraged environmentalists, railroad rights of way, and wages; they KNOW whose coal it is -- and they tend to be a little impatient with high-level discussions about what "we" ought to do with "our" coal.

Western coals in general have two other characteristics, besides high volume and modest energy-content, that puts them in the news these days. One is that they have a relatively low sulfur content; and the other is that much of the coal occurs in beds relatively close to the surface, and in such "luxurious" thick seams as to bring tears to the eyes of an eastern underground coal miner. In Montana alone, our Bureau of Mines and Geology estimates there are some 45 billion tons of strip-pable coal -- that is to say, no deeper than 150 feet, and with seams thick enough so the ratio of overburden to coal thickness doesn't go beyond a feasible 30/1. This does not include, by the way, the sizable deposits in 2 of Montana's 7 Indian reservations.

Underground mining of coal -- besides furnishing problems for engineering students in Descriptive Geometry -- was once the accepted way of getting coal out of the ground, but has gradually given way to surface mining since about 1920, when there was almost none. By 1973, half of coal mined in this country came from surface mines. Historically, deep

mining has been more costly in deaths and injuries, and because it requires leaving part of the coal in place to support the overburden, its rate of recovery will probably always be lower than that of surface mining. Its productivity in tons per man-day has slowly lost ground compared to surface mining. In 1964, average production per strip-coal miner was 2-1/3 times as high as his underground counterpart. By 1974, it was 3-1/3 times as high, or about 37 tons. Part of the reason for this difference is machines like the dragline shown in Illustration #3. The most recent versions of this monster costs three or four million dollars on the hoof. It is so big that it must be assembled on the job; and if you wanted to order one, you'd have to get in line, because the lead time is currently around 6 years. But it is these machines that have changed the image of the coal miner from the grimy man with a carbide lamp on his hat, coal-dust in his lungs and a pick in his hand, to that of a heavy-equipment operator seated in the cab of a dragline, a mammoth coal shovel, a bulldozer, or a dump truck. Coal in a modern strip-mine is rarely even touched by the coal miner.

The major problem with strip mining, however, is that as the name implies, it chews up the land at a rather horrendous rate. One Montana historian in a recent book calls it "the rape of the Great Plains." If all the 45 billion tons of strippable coal in Montana were actually produced, it would involve disturbing over a million acres. That is nearly 1 1/4 percent of the total area of the state -- but because all the strippable coal is in eastern Montana, it represents three times that proportion of the part of the state that is involved. In any case, a million acres of spoil piles would be an intolerable cost if all of it was to be left in sterile heaps like some of the areas around the town of Colstrip, which

were left untouched for 30 years or so after the railroad went to diesel power. As a matter of fact, both federal and state laws now require at least some attempts at reclamation of the land so disturbed. Montana requires that any company proposing to strip mine coal first present a mining plan to the State Department of Lands, and show just how it proposes to restore the land to something like its previous productivity -- whatever that was, and however long it takes. Burlington Northern, although it was not subject to this law, has been working since 1971 to try to undo the mischief wrought by its predecessors on a thousand acres of spoil piles at Colstrip, by smoothing the steep slopes to more undulating contours, and planting a variety of grasses, forbs, shrubs, and even trees. In some areas, it has experimented with adding topsoil, mulching, fertilizing, and watering.

The question is, can the land so disturbed ever really be reclaimed; and the answers are many and varied. Most mining companies that have made attempts at reclamation have some areas to which they can point with pride -- and do so in four-color advertisements. Most of them have other areas they would just as soon not advertise, and it is these sites that are generally called attention to by the advocates of no-strip-mining. An over-exposed Kodachrome shot of such an area taken on a dreary day in early winter before the first snows, can go a long way toward "proving" that all attempts at reclamation are doomed to failure. And when you start with terrain, like so much of our western lands under which coal occurs, whose vegetation was not exactly lush to begin with, the process of establishing a self-renewing habitat is bound to be difficult.

Now, of course, not everyone wants to see this land returned exactly

as its previous ground cover and productivity. Most of these coal lands are now classed as rangeland. There have been some fairly heart-rending protests at the prospect of destroying all this climax vegetation that provides range forage; but the fact of the matter is that in our state at least, that land on the average is returning somewhat less than 10 cents an acre in taxes. At 30 or 40 thousand tons of coal to the acre, at \$7 a ton f.o.b. the mine, and with our 30 percent severance tax, it is returning around 70 thousand dollars an acre as coal land. So it is not surprising that some ranchers, when they talk about reclamation, are saying "climax vegetation be damned -- with that kind of money it should be possible to establish something that would support a lot more herefords to the acre (or in some cases, a lot less acres to the hereford) than the natural vegetation ever would."

The argument is not likely to be settled soon. One Montana author writes that it has been "proven historically" that reclamation must fail. This is rather like saying, in 1960, that it had been proven historically that man cannot go to the moon. One geologist makes a really convincing case for the fact that the delicate plains topsoils took centuries to develop naturally to their present state, and that restoring those micro-layers, once they are disturbed, would have to be done with tweezers and a microscope -- never with a bulldozer or a dragline.

What it comes down to is that the success of reclamation is a highly individual affair for each mined area, and what works for Colstrip, Montana, doesn't necessarily hold true for Decker, Montana, or Sheridan, Wyoming, or Arizona -- and vice versa. It is certainly

true that the laborious and apparently highly successful reclamation of coal lands in such places as the Ruhr Valley cannot be used to draw conclusions for the semi-arid western rangelands of the U.S.A. It is also predictable, I'm afraid, that making sure of conscientious efforts at reclamation will require that coal mining companies be nudged along by state regulations enforced by state watchdogs -- and that almost no efforts are going to be regarded as completely successful by everyone concerned.

This brings us to the question what, if anything, is to be done with all that coal we have. It seems quite likely that much of it is going to be used. Mr. Kleppe has just issued a set of proposed regulations having to do with starting up once again leasing the vast federally owned western coal lands. California and other states are considering slowing down -- even phasing out -- of the development of nuclear power, which means coal or something else will have to be substituted. In spite of tighter regulations concerning the mining and use of coal, we seem headed for considerable acceleration of coal mining one way or another.

This flies in the face of the opinions, to be sure, held by quite a few people that the best possible use of coal is to leave it right where it is, holding up the overburden -- or at least to leave it where it is until future generations come up with wiser and better decisions as to how best to use it. This may be a forlorn hope, for it is hard to prove, for example, that we are much wiser than our ancestors in making this sort of decision.

Another class of decisions, if you are going to mine the coal, concerns where it should be used. Most areas in which it occurs in

the west are in rather sparsely populated regions; and if you bring large conversion plants to where the coal is, you create profound changes in the way of life of communities and groups of people who are not at all enthusiastic about having their lives disrupted in a number of ways. Traditionally, we have rather simple-mindedly equated growth with progress; but as you well know, there are a lot of things about growth that can't really be called progress at all, and a lot of folks are rejecting growth for growth's sake. As to the comparative economy of either generating power at the mine mouth and transporting it over wires, or else transporting the coal by unit trains to generators located where the people and markets are, there is considerable disagreement and a lot of conflicting evidence. For one thing, rails and roadbeds designed for mixed freight and passenger service are taking a terrific beating, I am told, from the heavily loaded coal trains shuttling over them; and I am not sure the stepped up maintenance costs of this unusual service are being built into the calculations that seem to show it is cheaper to transport coal than power.

An alternative, of course, is to transport coal as a slurry in a pipeline. Not surprisingly, the railroads have not welcomed this solution; and since much of our western coal is located in areas of sparse rainfall, this would seem like an improvident use of already scarce water supplies. Actually, however, it turns out that the amount of water sacrificed by a coal slurry pipeline is a whole order of magnitude less than that required for conventional generators or coal conversion plants. Among others, Colorado School of Mines is experimenting with a scaled-down version of a slurry line at Boulder.

Conversion of coal brings a bewildering range of possibilities,

which could easily occupy the rest of this conference if there weren't so many other fascinating things to talk about. Take gasification, for instance -- which usually means chemical conversion of the carbon in coal to a mixture of gases that is comparable to the energy content of natural gas or methane.

There are literally scores of methods that have been suggested or experimented with to bring about this transformation. The current front runners, however, according to their acceptance for federal funding and concentrated developmental research, carry such names as the Hy Gas process, or Bi-Gas, or CO₂ Acceptor, or Synthane. There is only one, though, that is actually in commercial use. This is the German Lurgi process, which goes from coal to high-energy gas -- around 1000 Btu per cubic foot -- in two stages. Plants for achieving the first stage, ending with low-Btu gas comparable to the coal gas that once lighted most American cities, have been operating in Europe and South Africa for years. The last stage, called Methanation, has never actually been scaled up to the volumes necessary to feed a modern high pressure interstate gas line (around 250 million cubic feet per day). There is a nearly full-scale methanation experiment going on now, by the way, somewhere in Scotland, financed by a number of American gas companies and others, who are watching the results this year with great interest. I'm sure there are a lot of trans-Atlantic trips being taken by gas company engineers this spring and summer that are being justified because the itinerary includes a trip to Scotland for a careful look at the methanation experimentation.

There is not time enough here for more than a quick and highly unauthoritative summary of some of the characteristics of these competing

processes for making SNG or synthetic natural gas. The Office of Coal Research is funding research by the American Gas Association and the Institute of Gas Technology in Chicago, on the Hy Gas process. It is also behind the research on Bi-Gas process by the Bituminous Coal Research Laboratory in Monroeville, Pennsylvania, and the CO₂ Acceptor process research being done in Pittsburgh by Consolidation Coal. Its sister agency, the Bureau of Mines, is backing research on the Synthane process. All these, I believe, are now in some stage of pilot-plant testing, but none has as yet been scaled up to full commercial operating size.

All these processes involve exposing coal of some variety, in one physical form or another, to steam at pressures ranging from 20 to over 70 atmospheres in a gasifier vessel. The result is a mixture of wanted and unwanted gases, part of which are stripped and rejected, part left alone, and part converted to a more useful form. The methanation step, for example, combines some of the hydrogen produced in the gasifier, with some of the carbon monoxide, in the presence of a catalyst under heat and pressure, and produces methane and water vapor.

Variations among the processes have to do with what kinds of coal can best be utilized, how it is treated before the gasification begins, the pressures and temperatures used, as well as the source of process heat, the output of waste products and by-products; and most importantly, the cost and efficiency. Unfortunately, the Lurgi process, although the only one proven in actual use, is neither as efficient nor as economical as most other processes under study promise to be -- if they get past the pilot stage. It is quite possible that what seems like a lot of duplicate research on processes competing to turn out the same final

product, will actually prove to be wise planning, and that no one process will be the best for all coals and all situations.

Synthetic natural gas is not the only fuel that can be produced by converting coal. It can also yield liquids varying from alcohol to synthetic crude oil. About half the electric power in this country is generated in plants fueled by gas or fuel oil, both of which could be replaced by non-polluting fuel oil derived from coal with virtually no plant changes -- if it could be produced at a price the plants and their customers could afford. There are at least three kinds of direct liquefaction processes that could be used; but all of them require heavy pressure vessels, and heavy infusions of venture capital. The latter is in short supply, and the waiting line for heavy-walled pressure vessels is currently around four years long. It is not at all clear that a large commitment to this form of coal conversion can be made and still stay within air quality standards of the federal government, let alone some of the still more stringent state standards.

Finally, there are a number of processes that modify coal by solvent refining or pyrolysis -- driving off gases by heating the coal in a vessel in the absence of oxygen -- to produce a solid substance like coke that burns more efficiently and with less undesirable effluents. These processes are still experimental, though, and even though they yield other useful products, the costs are still somewhat discouraging.

There are some dedicated research engineers right now up in Montana and elsewhere, however, who are asking the question, instead of using a lot of energy to convert it why not burn the coal? These people are concerned with a process that goes by the jaw-breaking name of Magnetohydrodynamics -- mercifully shortened to MHD. This is a method,

particularly when it is combined with conventional steam-driven generators, that promises to wring out more of the energy contained in coal and convert it to electrical power.

It was Michael Faraday who is credited with the discovery that when you move a conductor (like a copper wire) through a magnetic field, you induce an electric current in the conductor. When you wrap that conductor in an armature around a shaft which is rotated between the poles of a magnet (Illustration #4), either by water power or an internal combustion motor or a gas turbine, you have the dynamo which is the basis of all the electrical power produced in this and other countries. It was an incredibly useful discovery. But it was the same Faraday who also noted that the conductor need not be a wire; it can also be a conductive gas.

Now consider what that can mean. When you burn coal and heat a boiler, of course, you lose some of its energy. When that boiler turns water to steam, it loses some more energy; and when that steam turns a heavy rotor, you lose still more. But in an MHD generator there is no steam and no rotating machinery. The hot ionized gas from burning coal is made still more conductive by "seeding" it with metallic salts, and it is forced at high temperature and high speed through a long passage surrounded by a magnetic field, and containing electrodes that pick up the electric charge in the form of direct current, which is then converted to alternating current. Already the process is more efficient than the conventional steam generator with pollution controls. But now the seed material is recovered (it's too expensive to waste) from the gas, whose temperature is still around 3000 degrees. Most of the remaining energy in it can be recovered by using it to make steam and

drive a conventional turbine generator. Theoretically, the efficiency of the combined processes can reach 50 to 60 percent -- compared to something like 35 percent efficiency of the steam generator with the necessary pollution control equipment.

There are other potential advantages to MHD. In the process of recovering that seeding material, the gas must be thoroughly cleaned, so that what is finally sent into the atmosphere is considerably cleaner than the effluents emitted by present plants. Because the MHD generator uses no water except for the steam-generator portion, the process seems well suited to water-short areas here in the west; and if plants were carefully situated near business, manufacturing plants or homes, the waste heat remaining in the gas could be used a number of ways.

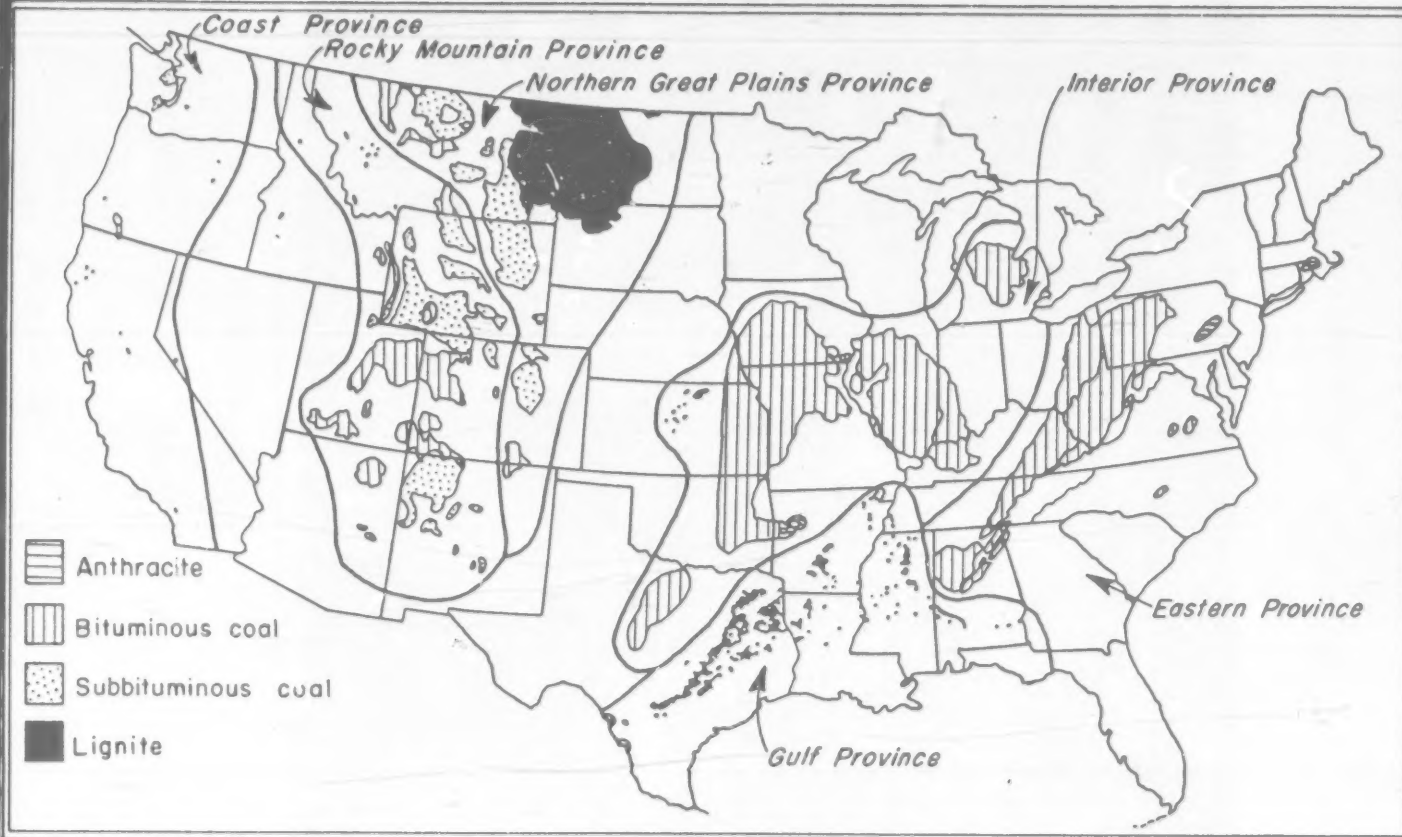
Before we get carried away with enthusiasm for this process, however, let it be noted that there are a number of problems to be solved before it will be ready for commercial use, and we hope a lot of those problems are going to be licked in Montana. Ground has been broken in the city of Butte for the first of several pilot plants, and if all goes well, by the mid-1980's the plans call for a commercial sized demonstration power plant with a capacity of about 500 megawatts.

In this quick review of some of the ways either to convert coal to another form of fuel or to a more usable form of energy, I have among other things left out what is called in situ gasification, and the fuel cell. The processes that convert coal to gas, you remember, require a steel pressure vessel. But given the right kind of geological formation around an underground coal seam, it is possible to use the earth itself as a pressure vessel, and so skip the coal mining step. Since the product is low-Btu gas, which cannot profitably be pipelined

far from its source, it would probably have to be used, or further converted, near where it comes out of the ground.

The fuel cell -- or at least one version that shows most promise -- creates electrical energy by a process that is the reverse of hydrolysis. The hydrogen fuel cell, which has gotten most attention, combines hydrogen and oxygen through an electrolytic cell, releasing some electrons and so creating a current through an external circuit. The process is as soundless as a wet-celled battery, and creates virtually nothing more noxious than water. It can be operated efficiently at less than maximum output, so theoretically it should be adaptable to modest-sized units that could be widely dispersed. But the source of the hydrogen in experiments by Pratt Whitney Aircraft and the American Gas Association is natural gas -- the supply of which is limited and dwindling. When you have to convert coal to methane, then split out the hydrogen in order to run the fuel cell, unfortunately cost makes the process much less appealing, even if the remaining "bugs" are taken out of the system.

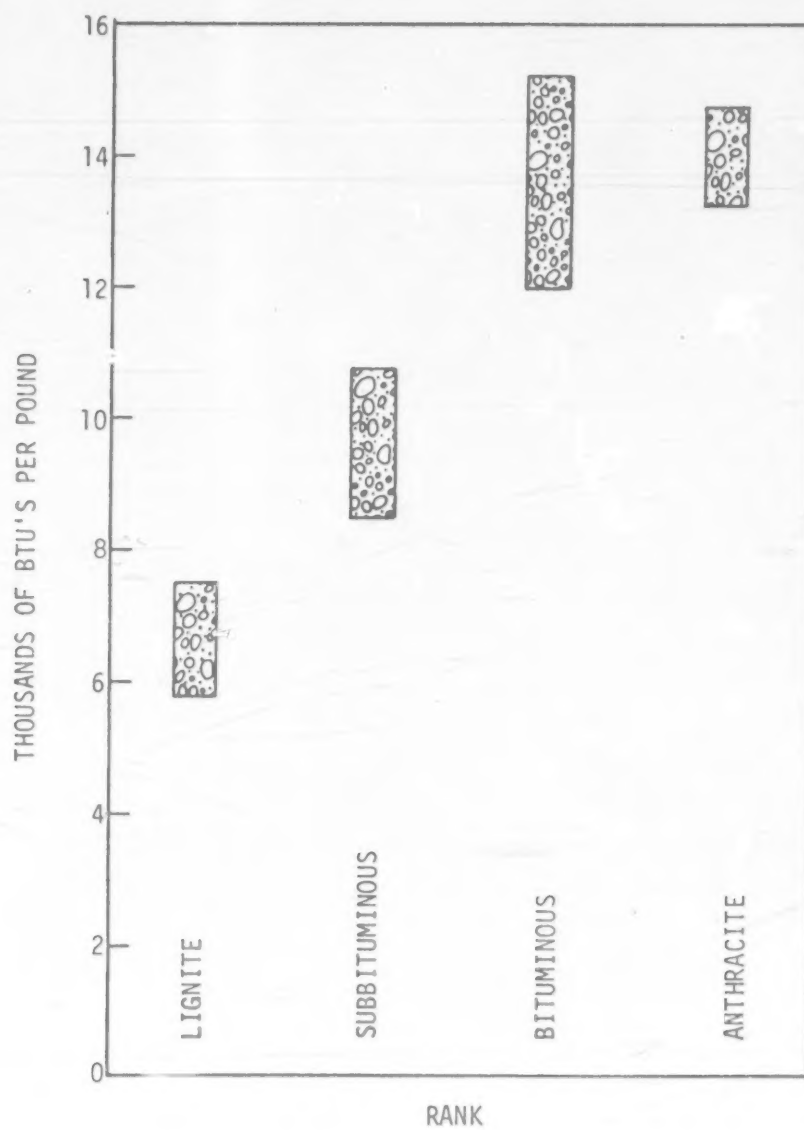
And on this gloomy note, I'll close and defer to the lunch hour.



Distribution of United States Coal Resources

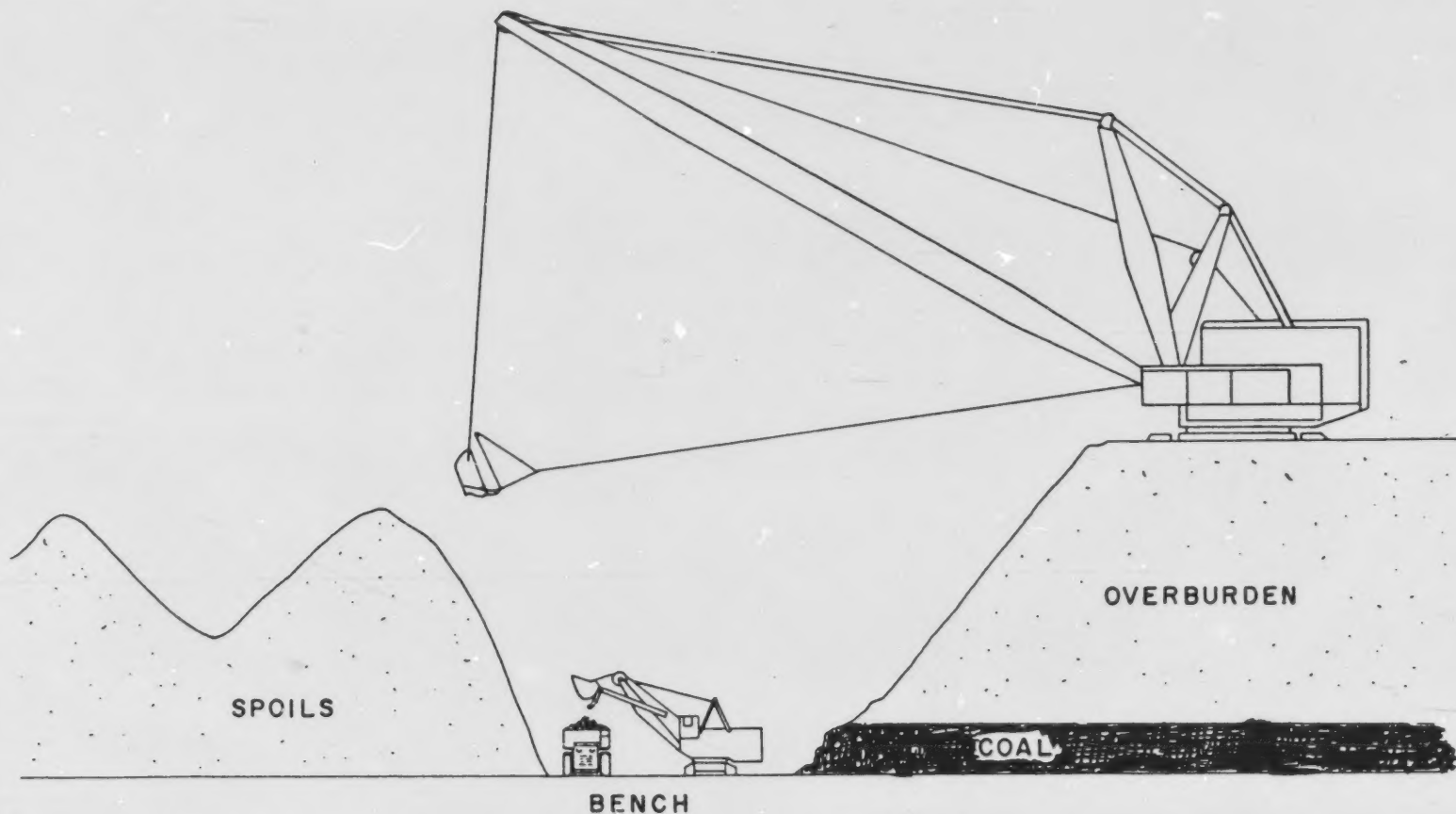
Source: BLM, 1974: I-47

ILLUSTRATION #1



Heat Content of Major Coal Ranks

ILLUSTRATION #2



Area Mine

Source: Adapted from NPC, 1972: 51.

ILLUSTRATION #3

PISTON ENGINE GENERATOR

GAS
FLOW

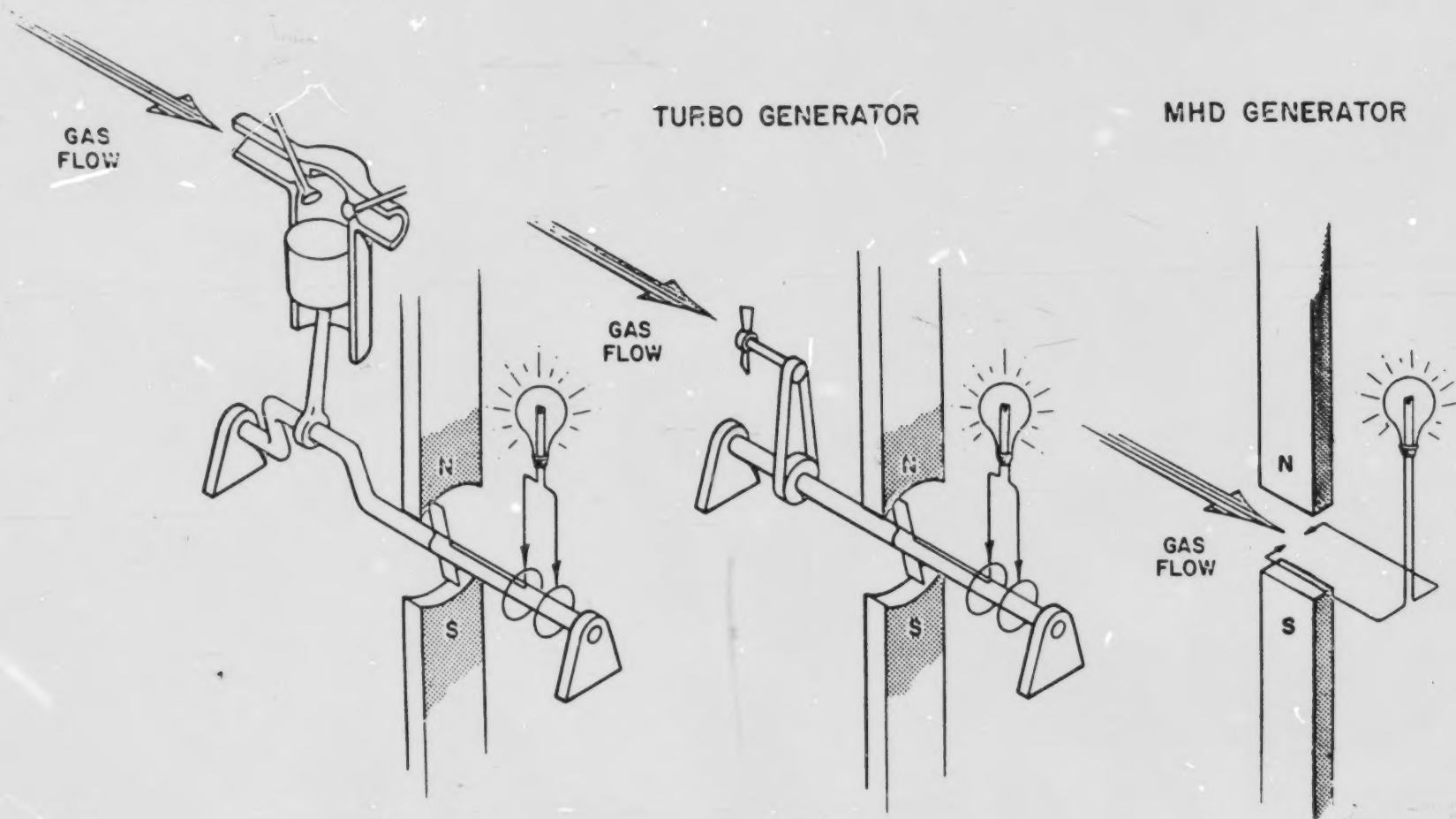
TURBO GENERATOR

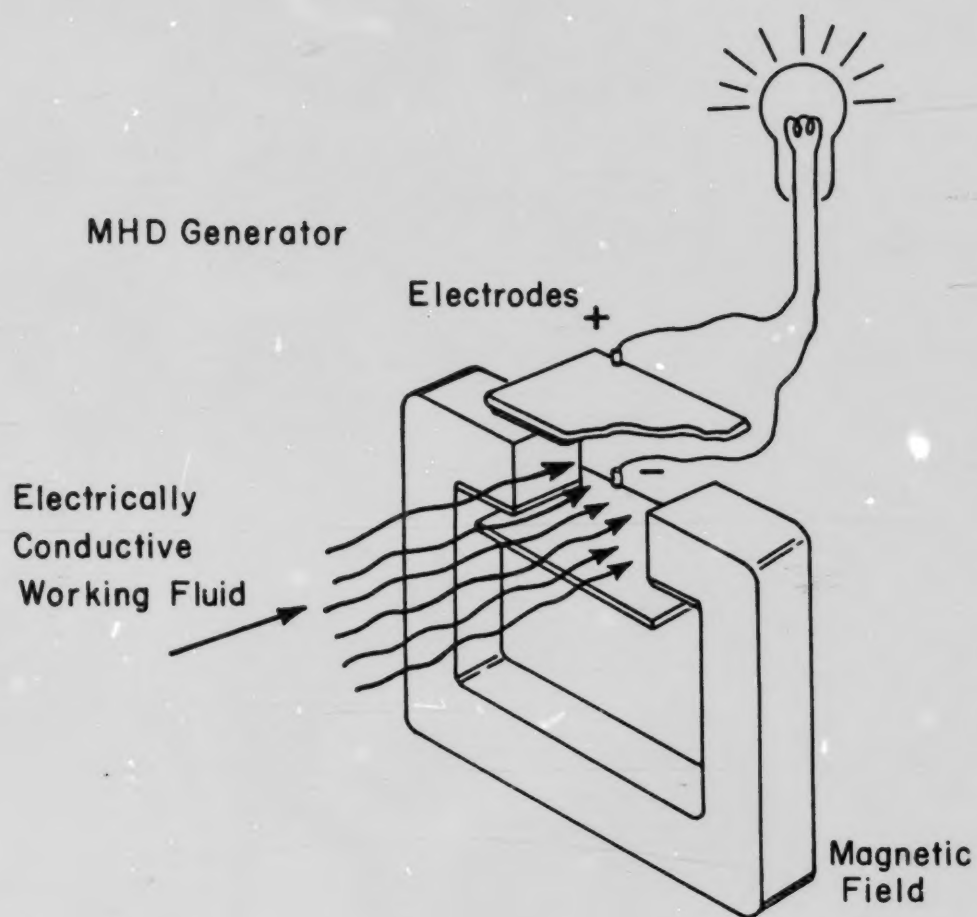
GAS
FLOW

MHD GENERATOR

GAS
FLOW

ILLUSTRATION #4





MHD Generator Electrical System

Source: AEC, 1974;

ILLUSTRATION #5

GAS AND OIL:
NATURAL GAS, SNG, OIL, OIL SHALE AND TAR SANDS

By
JOHN BANNISTER

Executive Secretary
Oil and Gas Conservation Commission
State of Arizona
8686 North Central, Suite 106
Phoenix, Arizona 85020

GAS AND OIL:

NATURAL GAS, SNG, OIL, OIL SHALE AND TAR SANDS

It is indeed a pleasure to appear before you today. The assigned subject of this address is "Gas and Oil: Natural Gas, NSG, Oil, Oil Shale and Tar Sands". I have taken the liberty of somewhat spilling over into the subjects to be covered by later speakers; however, I assure you it will be brief.

America contains 6% of the worlds population and uses one third of the worlds energy. Have you heard this statement and seen these figures? If so, I hope this statement upsets you as much as it does me. I can see no reason why America should feel ashamed of itself for its past performance. Consider, in just 200 years America has given its people the best standard of living in this world. We have fed half the world and we are the only nation to open its heart and its supplies to the world wherever disaster or famine occurs. Two world wars have been fought primarily on American energy with the idealistic reasons of making this a better world in which all people could live free. Following both wars, billions of our dollars have gone to rebuild the ravished lands of our enemies, as well as to rebuild the land and economy of our allies. Our oil has gone to every country of the world - at reasonable prices.

America has gone out into space and has actually landed its pioneers on the moon and brought them back. To me, our America has nothing whatsoever to be ashamed of in its use of its own energy.

I would like to digress here for a moment and tell you a small story concerning the use of American energy abroad. Perhaps you have heard the expression "Oil for the Lamps of China". This refers to our expanding oil industry at the beginning of the 20th Century when millions of Aladdin-like lamps were distributed free throughout China and the surrounding area, thus creating an illumination market to be served by vast amounts of American kerosene.

We hear so much today about energy - shortage of energy - etc., so let us examine for a moment just exactly of what we are speaking. Energy is simply heat and the most accepted measure of heat is BTU - the British Thermal Unit - which is the amount of heat required to raise the temperature of one pound of water (one pint) 1°F. To reduce some of our more recognizable sources of energy into the BTU measurement, the following table may be of interest:

1 Barrel of Oil (42 gallons)	=	5.8 Million BTU
1 Ton of Coal (1 Ton of Coal is equivalent to about 5 Barrels of Oil)	=	26.0 Million BTU
1 KW of Electricity	=	2,412 BTU
1 Cubic Foot Natural Gas	=	1,000 BTU

As you are well aware, man's first use of energy was furnished solely by his own muscle power and somewhat later to this was added the muscle power of domestic animals. As man progressed and learned the use of fire, various natural fuels came into prominence.

In the United States, the use of wood as our primary fuel peaked at approximately the year 1850 and, at that time, coal began to surpass wood as our most abundant and useful fuel. This cycle continued until approximately the year 1910, when coal, at its peak, began to be replaced by the still more convenient fuels - oil and natural gas. The use of oil as our prime fuel peaked at approximately the year 1970. You will note that these prime fuels have enjoyed a life of approximately sixty years. If this cycle continues, it is to be expected that during the next sixty years some other fuel will become our prime energy. This next sixty years is crucial.

Most of us are familiar with the history of our current oil and natural gas crisis. Briefly, as the convenience and abundance of oil grew, America's energy demands looked more and more to this "cheap" fuel. As heating for the home, oil could be delivered and put into a tank, a valve turned on and, without handling the product, heat could be furnished to your home. The coal bin was eliminated. Industry turned rapidly to this convenient and cheaper source of energy, as did our transportation industry. Of course, the abundance of oil and gasoline, together with the Model T Ford, put America on wheels. Consequently, during this period of growth, oil began displacing coal as the prime fuel of the nation and, as the result, the coal operators ceased much of their activity to locate new sources of coal and to open new mines. The demand simply was not there.

As a by-product of the oil industry, natural gas, at first an undesirable waste product, became more abundant and, as its blessings became more known, it began to rapidly erode the market established by oil and made further inroads upon the coal market. Natural gas was the ideal fuel - it required no storage, was always on hand on demand, just as water is available to you in the spigot, natural gas was available by merely turning it on. Natural gas was cheap. Natural gas was clean and desirable. It left no undesirable environmental impact. Consequently, the demand for it grew rapidly.

Primarily in response to the political demand of the northeast portion of our country, the Federal Power Commission was created to protect the have-not states from the possible price demands of the producing states. This has had great repercussions. The Federal Power Commission is charged to control the price of this product and to see there is a continuous supply. As a result of the Federal Power Commission's activity, natural gas is held at an artificially low price, consequently you find the most desirable fuel held at an unrealistically low price and, of course, the demand for this fuel continues to skyrocket. The natural gas industry found itself in the position of, say, a candy manufacturer who made the most popular of all candy bars, the production of which cost him

10¢. Due to the large consumption of the bar, the government ordered him to meet all demands and to sell his bar for 5¢. You cannot blame this manufacturer for not having an economical incentive to enlarge his plant, find more chocolate, etc., for his production. In short, the Federal Power Commission placed the natural gas industry into a position where a fair rate for its product simply was not there.

Of course, the demands for natural gas at the artificially controlled price began to displace the more available, but more costly, fuel oil. It is interesting to note that for the past twenty years the oil industry has been trying to explain to our political leaders, to its consumers, and to anyone who would listen, that this condition could not continue without creating the situation in which we find ourselves.

Let us take a look at oil, itself - what is needed to run this country of ours - just what will oil do -

1 Bbl Oil - Heat an average home 4 days

10 Bbls Oil - Drive car round trip NY - LA

100 Bbls Oil - Jet Washington, D.C. to Chicago

1,000 Bbls Oil - Run City Baltimore 10 minutes

1,000,000 Bbls Oil - Run California 8 hours

United States uses 17 million barrels of oil per day.

United States produces 8.5 million barrels of oil per day.

United States uses oil, gas, coal, electricity, hydro-electric, nuclear - all sources equivalent to 32 million barrels per day.

Oil goes -

47% to cars, trucks

24% distillate home heating

9% jet fuel

8% residual heavy fuel (industry & utilities)

8% lube oils

4% refinery operations

Federal Energy Administration estimated reserves:

38.2 billion barrels oil

237.0 trillion CF natural gas

To be found - ?

105 billion barrels oil

636 trillion CF natural gas

In the year 1975, the worlds major energy was supplied by oil - 45%; coal - 26%; natural gas - 20%; hydro power - approximately 7%; geothermal and nuclear energy - 2%. It is interesting to know that from 1960 to 1975 the use of oil increased from 35% to 45%, while coal decreased from 45% to 26%. Natural gas increased from 15% to the current 20%.

As you are well aware, the United States now finds itself in the "energy crises". In spite of all our efforts, demands for energy, not only in the United States but in the world, will continue to increase. Although we have an abundance of coal, it is not readily available. Many mines need to be developed and opened - a transportation system needs to be created to deliver coal once it is extracted. The capital requirements will be staggering.

The problems associated with nuclear energy are well known and, should we be able to start immediately to construct nuclear plants without further consideration of the problems of environment and safety, it would be some five years minimum before a new plant could go on stream. Considering environmental requirements, this length of time could be as much as ten years.

Geothermal energy, as you will later see, is not expected to make a major contribution to the United States, although it certainly will be developed as rapidly as possible. Estimates range from 1% to as high as 10%. I, personally, feel 1% to 3% is in the ball park.

Solar energy is, as yet, in the future and is yet to show itself to be economical.

So - what can we do in the interim? You hear much of the word "conservation". In my opinion, conservation, as such, is the impossible dream. In spite of efforts to slow down cars, turn off lights, use less air conditioning, etc., no sizeable amounts of energy have really been saved. Conservation of energy, as used primarily by government officials, is a method of sharing the shortage and does not meet the real problem, that is, increasing the supply of energy that we need. But, we must not overlook the fact that conservation of energy should become the aim of every person. Let us look at some of the other alternatives available to us:

Oil Shale

Oil shale, a fine-grained sedimentary rock containing insoluble organic matter that yields substantial amounts of oil by destructive distillation, occurs in large volumes throughout the United States and the world, and constitutes an enormous resource of oil. Identified resources of shale oil in the United States total about 2 trillion barrels of oil in shale that yield an average of 15 or more gallons of oil per ton, most of which is in the lacustrine rocks of the Eocene Green River formation of Colorado, Utah, and

Wyoming. Although no oil is being produced from oil shale in the United States, it seems likely that oil from high-yield shales will be needed in the near future to supplement other sources of energy. It is estimated that 0.42 trillion barrels of oil are in oil shale that yields 30 or more gallons of oil per ton, 85 percent of which is in western Colorado. Minerals locally associated with the rich oil shale may yield recoverable sodium carbonate, sodium bicarbonate, or aluminum.

Marine black shales occur in many parts of the United States and form an immense, but low-grade resource of shale oil. The better parts of these deposits generally yield only 10-15 gallons of oil per ton, but hydrogenation or similar techniques may increase the yield by 50 to 100 percent. Another widespread resource of shale oil may be the carbonaceous shales associated with coal beds. The total resources of shale oil to depths of 20,000 feet may total 26 trillion barrels in low-yield shales and 1.3 trillion barrels in high-yield shales.

Shale reserves in the western United States may account for as much as 500,000 barrels a day of oil production by 1985. But environmental and cost problems may limit shale's role as a major energy contributor in this century.

Various pilot programs are being tested. One uses underground mining and above-ground retorting, and the first commercial shale projects are likely to be of this kind. The process involves crushing and heating the mined material to break down the hydrocarbon deposit called kerogen, which is present in the shale. Treatment with hydrogen is required to convert the kerogen-derived shale oil to synthetic crude oil. In situ processes, using explosives to create rubble-filled cavities that serve as underground retorts, are also under investigation.

Problems of shale development include:

The size of the operations involved. Whereas the largest underground mine in the United States produces about 5 million tons of coal per year, underground mining of shale would have to produce 55 million tons of shale a year to supply a 100,000 barrel-a-day shale oil plant.

Disposal of the spent shale. With above-ground retorting, this will be considerable concern. The shale increases in volume during mining and retorting, so that not all of it can be put back in the mine.

Water requirements. Large quantities of water would be needed to process the shale, as well as to wet it down afterward, so as to settle the dust and prepare for revegetation.

Overall cost of production. With existing technology, synthetic crude oil from shale will be much more expensive than conventional oil.

SHALE-OIL RESOURCES OF THE UNITED STATES, IN BILLIONS OF BARRELS, BY GRADE (OIL YIELD) OF OIL SHALE

(All resource figures except those for the Green River Formation are adapted from Duncan and Swanson, 1965, table 2; Ne, not estimated)

Deposit	Identified ¹		Hypothetical ²		Speculative ³	
	25-100 gal/ ton	10-25 gal/ ton	25-100 gal/ ton	10-25 gal/ ton	25-100 gal/ ton	10-25 gal/ ton
Green River Formation, Colorado, Utah, and Wyoming - - - - -	⁴ 418	1,400	50	600	---	---
Chattanooga Shale and equivalent formations, Central and Eastern United States - - - - -	---	200	---	800	---	---
Marine shale, Alaska - - - - -	Small	Small	250	200	---	---
Other shale deposits - - - - -	---	Small	Ne	Ne	600	23,000
Total - - - - -	⁴ 418	1,600	300	1,600	600	23,000

¹ Identified resources: Specific, identified mineral deposits that may or may not be evaluated as to extent and grade, and whose contained minerals may or may not be profitably recoverable with existing technology and economic conditions.

² Hypothetical resources: Undiscovered mineral deposits, whether of recoverable or subeconomic grade, that are geologically predictable as existing in known districts.

³ Speculative resources: Undiscovered mineral deposits, whether of recoverable or subeconomic grade, that may exist in unknown districts or in unrecognized or unconventional form.

⁴ The 25-100 gal/ton category is considered virtually equivalent to the category "average of 30 or more gallons per ton"

Tar Sand

Tar sand is a loose term that is applied to any oil impregnated rocks, including limestone, dolomite, igneous shale, conglomerates, sandstones and others. Tar sands are found in many parts of the world. The major known deposits are found in the province of Alberta, Canada. Estimated at 895 billion barrels of oil in place. The Orinoco Region in Venezuela has an estimated in place volume of 700 billion barrels. Smaller accumulations are found in various places in the United States.

In Utah, there are 24 tar sand deposits that have been studied in enough detail to establish the existence of a substantial oil reserve, 27.5 - 28.7 billion barrels of oil. Seventeen (17) of these deposits are found in the Uinta basin in northeastern Utah and contain 10 - 11.3 billion barrels of very viscous oil, most of which is less than .5 of 1% sulfur. Lack of effective technology for recovering oil from the tar sands has prevented their utilization as an oil resource in the past; however, small scale mining operations have gone on for production of tar sands for direct use in road paving.

Much of the bituminous layers are under economically prohibitively deep ground cover. Only a small part of the sandstone can be mined by open-pit methods. The deposits, hopefully, are suited to the thermal recovery techniques. The thick uniform sands of the Mesa Verde group are the best target for the in situ recovery. Increased activity in the tar sand areas is the result of improved economics in these operations because of increasing oil prices. This greater interest is especially directed at the interest in bitumen recovery methods which are still marginal economically. As development of the in situ methods progresses, the production costs may be reduced to a level at which oil from bituminous sands can compete with oil from conventional sources.

Oil contained in these rocks originated from organic material contained within rocks laid down in situations in which the organic material was subsequently converted to petroleum.

In the formations of tar sands, the oil has migrated from the parent rock to become trapped in another locality.

With no impermeable rock to hold the lighter fractions of oil, the volatiles escape. The oil left in the sand is heavy viscous oil with a low gravity rating. The quality of oil may increase with distance from outcrop exposure and will increase with depth.

Tar sands are found by sight many times. They are uncovered in outcrops and in surface deposits. Tar sands can also be predicted from the known geological data of an area. When the formation overlaying the tar sand is fairly shallow, the tar sands can be mined and oil extracted from the sands at the surface.

Recovery methods include in situ combustion or fireflood, cyclic-steam stimulation and steam flooding.

In one in situ combustion process, air is pumped down an injection well to the producing zone. This is then ignited and a combustion front moves radially away from the injection well and drives oil, water and gas into the production wells. This oil is then recovered at the surface. Cyclic steam stimulation is done by injecting steam into a formation at a high rate for a few weeks. The well is shut in for several days so that the heat from the steam can be transferred to the rock and viscous oil removed. At this point, the well is allowed to produce and should show an accelerated rate of oil and water production for several months. The cycle is repeated when production reaches a low level. Steam flooding is a displacement process. Oil and water are produced from wells as a result of a continuous injection of steam into a selected well, and oil is produced from adjacent wells. Ultimate oil recovery from this displacement process can be as high as 35% from tar sand.

None of these methods of extracting oil from the tar sands has proved economically feasible with today's technology. An experimental project is recovering a small amount of synthetic crude from northeastern Utah tar sands, the Energy Research and Development Administration reported recently. ERDA says that about 50 barrels of oil have been recovered after four weeks of burning in thermal tests on a Sohio Petroleum Company property.

Tar sands are a doubtful future energy source for the United States. Although tar sand deposits are found in 14 of the lower 48 states, by far the largest known deposits are along the Athabasca River in the Canadian Arctic Circle. Estimates of potentially recoverable syncrude reserves in the Canadian deposits range from 175 to 300 billion barrels. The Great Canadian Oil Sands, Ltd., has achieved commercial operation of a 50,000 barrel-a-day plant extracting oil from tar sands, and others are planned. But major environmental problems will limit the pace of development, and it seems likely that Canada will want to hold on to most of the supplies that can be developed.

SNG

Synthetic Natural Gas

SNG is the general term applying to any gases that can be produced synthetically. Currently, the gasification of coal is far and away the most promising source of additional gas for our pipelines.

The blue water hydrogenation process seems to offer the most economical means of converting coal to a gas fuel. To accomplish this, an air blast is directed at a bed of coal until the coal reaches a temperature of 2192°F. At that time, the resulting

gases are captured and may be introduced directly into the natural gas pipeline for consumption. The slag remaining can be converted into fuel oil. It must be pointed out that this process varies from 60 to 90% efficient, that is, we lose from 10 to 40% energy.

A recent study by the Bureau of Mines predicts that the United States natural gas production will fall about 20% by the year 2000. (It is interesting to note the same study indicates that crude oil production will actually rise by 25%.) To make up the gas deficit, the Bureau of Mines now predicts that by the year 2000, 380 billion cubic feet per day of pipeline quality SNG will be available in the United States. This is a BTU equivalent of some 60 million barrels of oil.

The Energy Research and Development Administration envisions 100 coal gasification plants coming on-line over a 30 year span and ultimately producing 30% of the nation's energy requirements. They further predict this massive amount of energy will use up about 1% of the country's coal reserves. The Federal Government considers SNG of such overwhelming importance that President Ford is calling for a \$6 billion loan guarantee program for coal, gas and oil shale programs, guaranteeing up to 75% of defined costs for a coal gas plant. ERDA is planning to spend some \$1.15 billion to share costs with industry of three gasification pilot plants.

Let us now turn our attention to Arizona:

Energy in the State of Arizona is available from such sources as the sun (solar), wind, geothermal (heat contained in water, steam, and rocks beneath the earth's surface), water in man-made reservoirs (hydro-electric plants), fossil fuels such as coal, oil and gas, and uranium.

FIGURE 1. The map now projected on the screen shows tentatively defined gross areas in Arizona having varying degrees of potentialities for significant accumulations of petroleum. We do have two oil- and gas-productive areas in the state. These areas are near the extreme northeast corner of the state. They have produced about 15½ million barrels of oil and 15½ billion cubic feet of gas. Based on proved production, shows of petroleum in unsuccessful exploratory wells, and geologic conditions favorable for the generation and entrapment of petroleum, the horizontal dashed-line pattern shown in the Colorado Plateau province presently appears to have the most attractive potentialities for undiscovered petroleum energy resources.

As very few exploratory wells have been drilled for petroleum in the Basin and Range province, we do not know much about the geology of the rocks deeply buried in the valleys between the numerous mountain ranges. The sparse information available indicates that the patterned valley areas east of Tucson have the best potentialities for petroleum accumu-

lations. The potentialities of the dot-patterned valley areas in the balance of the Basin and Range province are almost completely unknown. The potential of the white areas in both provinces is zero except for improbable freak petroleum accumulations.

FIGURE 2. This map shows coal fields and occurrences in Arizona. Coal is the state's most naturally occurring fuel energy resource. The principal coal resources are on Black Mesa, a 3,200 square mile physiographic feature on Indian lands in portions of Coconino, Navajo, and Apache Counties. The other fields and occurrences shown on the map do not appear to contain resources of economic potential beyond possible local usage.

The Black Mesa field near the north end of the mesa has estimated coal resources in excess of 20 billions of short tons. Indications are that the total resources could be much greater, as most of the mesa remains unexplored. Contracts of the company operating the Black Mesa field specify an average delivery of 11 million tons per year over a span of 35 years to two power plants. One of these plants is in Nevada near Davis Dam on the Colorado River, the other at Page, Arizona.

In view of the nation's rapidly diminishing supplies of petroleum and steadily increasing dependence upon imported supplies, it seems likely that Arizona's large industries and utility companies eventually will turn to coal as an energy fuel. However, it should be mentioned that the Black Mesa is owned by Indian tribes, that at the present time there are no transportation facilities available for shipment of Black Mesa coal to Arizona's population centers, and that environmental groups are strongly opposed to the construction of new coal-fired electricity generation plants.

FIGURE 3. This map shows the approximate outlines of areas with unevaluated potential for low- to high-temperature geothermal energy-resource and the locations of hot springs in Arizona. In the basin and range province of southern and western Arizona, the geographic definition of these areas was based principally on geothermal gradient data (rate of temperature increase with depth) of numerous wells drilled for water. We do not know enough about these areas now to predict whether any of them contain temperatures sufficiently high ($320^{\circ}\text{F}/160^{\circ}\text{C}$ minimum) for the generation of electricity. Some of them, however, may have a potential for low-temperature geothermal resources. Heat for various uses can be extracted from water with temperatures greater than $117^{\circ}\text{F}/47^{\circ}\text{C}$.

The buried hot volcanic rocks in the San Francisco Peaks area north of Flagstaff in the Colorado plateau have an undetermined potential for geothermal energy resources.

FIGURE 4. This map shows reported occurrences of uranium in Arizona as of 1970. Most of these occurrences are in the Basin and Range province, but the most prolific productive area was the one southwest of Rock Point in northern Apache County in the Colorado Plateau province. Arizona played a minor but important role in the early development of uranium

supplies for the atomic energy program. By 1969, however, all mining operations had ceased as a result of the termination of Federal Government subsidies, depletion of the more accessible and richer deposits, and the closing of the uranium mills within reasonable transportation distance.

The known minable uranium resources of Arizona as of 1970 were insignificant in respect to the total amount estimated for the United States. As a result of large increases in the price of uranium ore during the past few years, Arizona is once again experiencing a uranium "boom". Several large companies and numerous small companies and individuals are actively searching for uranium deposits throughout the state. Unconfirmed reports indicate that appreciable quantities of ore are being found.

SUMMARY OF ARIZONA'S ENERGY PICTURE

1. RESOURCES

- A. Coal
 - 0.98 billion short tons strippable reserves
 - 20.27 billion short tons deep reserves (4130 feet)
- B. Oil
 - 4.7 million barrels proved reserve, 800,000/yr. production (1973).
- C. Natural Gas
 - 5.0 billion cubic feet proved reserve, 0.4 BCF/yr production (1973).
- D. Uranium
 - 125,000 tons U_3O_8 reserves of 0.4% U_3O_8 or greater - (1967), no production at present.
- E. Hydropower
 - 3010 MW total capacity, 875 MW available to Arizona including 147 MW pumped storage.

2. SUPPLIES

A. Electric Power Plant Capacity (MW)*

	<u>Hydro</u>	<u>Natural Gas/Oil</u>	<u>Coal</u>	<u>Other</u>	<u>Total</u>
Installed 12/31/74	875	1925	531	1576	4907
Scheduled 1975-80	---	----	<u>2547</u>	<u>389</u>	<u>2936</u>
Total 1980	875	1925	3078	1965	7843

*Includes shares available to Arizona from plants located instate only.

B. Annual net Natural Gas, present and projected (Trillion BTU's)

1973 - 196.2 actual	1976 - 133.0	1979 - 100.4
1974 - 174.2	1977 - 121.3	1980 - 93.6
1975 - 147.9	1978 - 109.8	

C. Annual Oil Consumption, present and projected (Trillion BTU's)

	<u>A</u>	<u>B</u>	<u>C</u>
1973 actual	315.0	315.0	315.0
1978	539.0	492.9	490.1
1980	600.5	514.2	505.0
1985	786.1	583.5	550.3

Present (1973) and estimated oil consumption under assumptions of rapid growth (A), slower growth (B), or approaching zero growth (C) in energy demand.

3. CONSUMPTION BY SECTOR, 1973 (Trillion BTU's)

	<u>Natural Gas</u>	<u>Petroleum</u>	<u>Coal</u>	<u>Hydro</u>	<u>Total</u>
Household/Commercial	67.8	9.4	*	---	77.2
Industrial	67.7	43.5	*	---	111.2
Transportation	24.7	198.2	--	---	222.9
Electric	58.3	56.3	42.8	71.9	229.2
Miscellaneous	<u>2.4</u>	<u>7.6</u>	<u>0.9</u>	<u>---</u>	<u>10.9</u>
Total	220.9	315.0	43.7	71.9	651.4

NOTE: All above tables from Helmut J. Frank, Arizona Energy Inventory, the Division of Economic and Business Research, College of Business and Public Administration, University of Arizona, February, 1975.

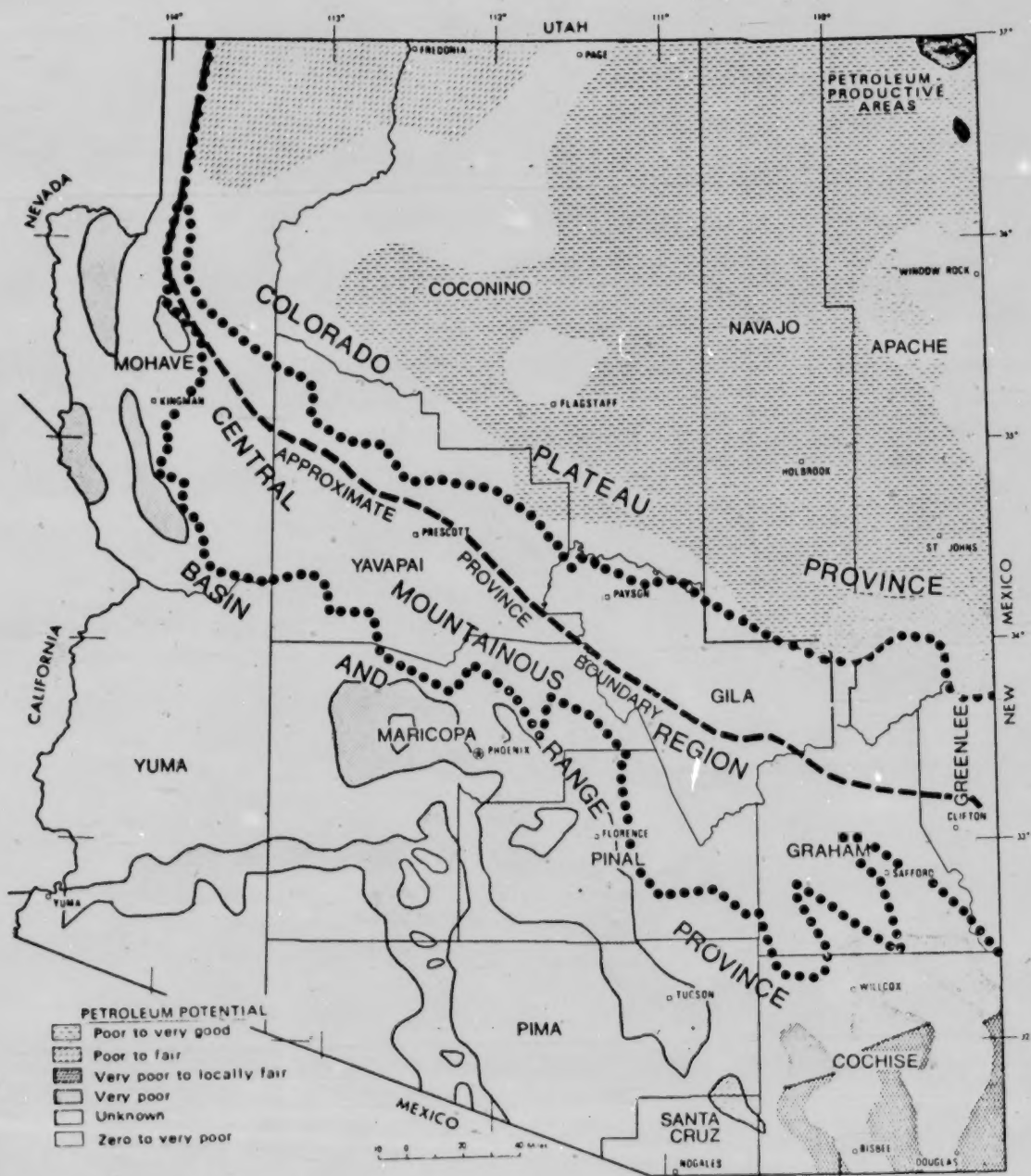


Figure 1. Map showing tentatively defined gross area having varying degrees of potentialities for oil and gas accumulations in the State of Arizona.

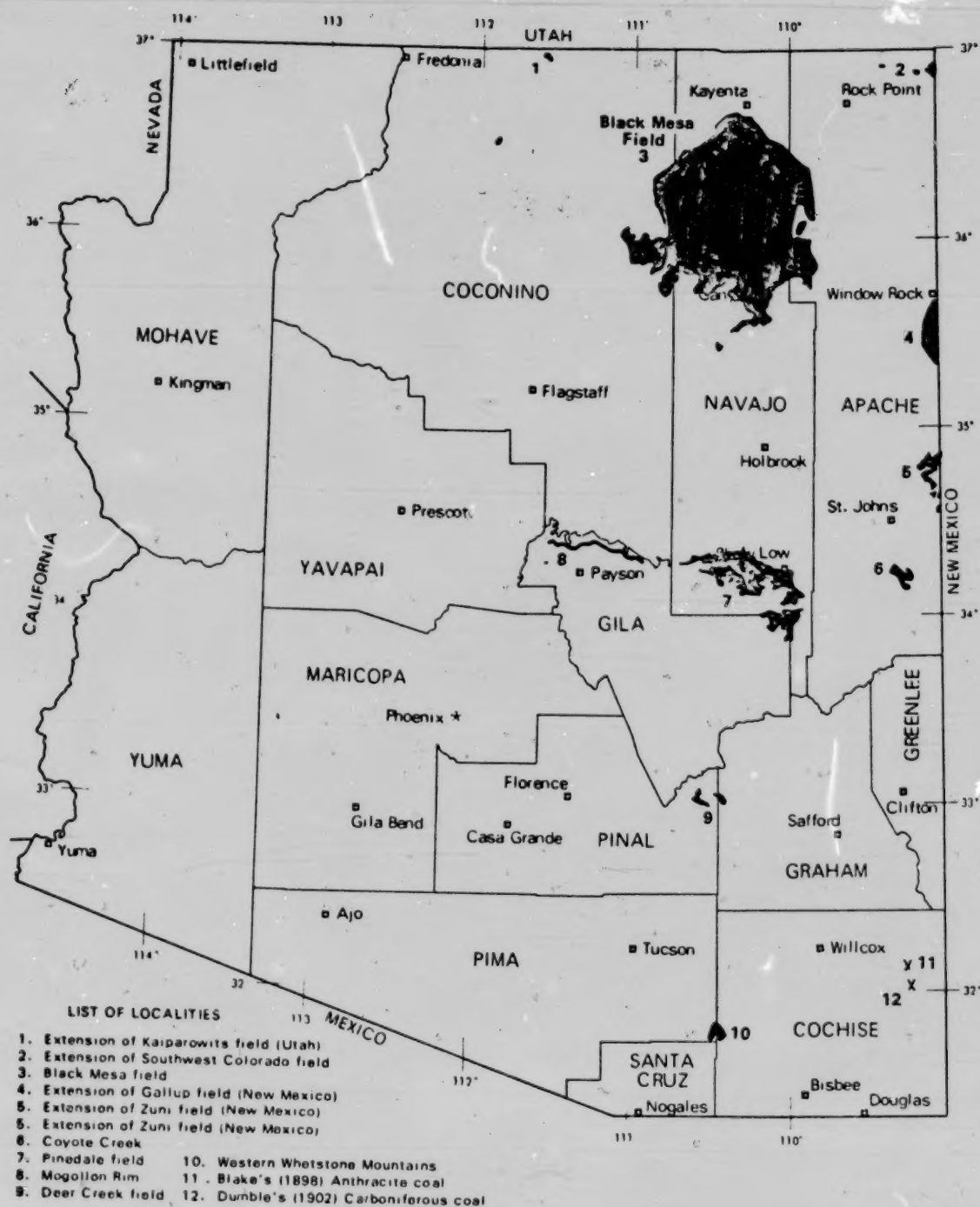


Figure 2. Map showing coal fields and occurrences in the State of Arizona (adapted from Figure 4, H. W. Peirce, S. B. Keith, and J. C. Wilt, 1970)



Figure 3. Map showing approximate outlines of areas with unevaluated potential for low- to high- temperature geothermal energy-resource based principally on geothermal gradient data of numerous wells drilled for water in the Basin and Range province of the State of Arizona.



Figure 4. Map showing reported occurrences of uranium in miscellaneous sedimentary rocks, diatremes and pipes, and veins in the State of Arizona (adapted from Plate 18, S. B. Keith, 1970).

Illustrations

Source

Figures 1 & 3

Arizona Oil and Gas Conservation
Commission

Figures 2 & 4

Arizona Bureau of Mines Bulletin
182

GEOTHERMAL ENERGY PERSPECTIVE

**By
STEVE ROGERS**

**Steam Generation Engineer
Pacific Gas and Electric
77 Beale Street
San Francisco, California 94106**

GEOHERMAL ENERGY PERSPECTIVE

I. TOTAL KNOWN RESOURCES AND RESERVES

A. Calculated Geothermal Resources

The heat content of the earth is immense. How much, no one knows for sure, but it is not conceivable that man could ever exhaust it, assuming he could find a way to make it all available. Much effort has been expended in estimating and guessing at the size of the geothermal resource. Many assumptions have to be made and one is never quite sure what mix of theoretical, practical and promotional elements may be contained in the estimates.

Some of the calculations of geothermal potential are reminiscent of an old high school chemistry exercise which calculated the weight of the gold in the sea. The calculation shows 56 pounds of gold per cubic mile of seawater which would be worth about \$130,000 at today's prices. With the sea containing over 320,000,000 cubic miles, its gold content is worth over \$41 trillion.

The real question, of course, is what can be extracted in a practical and economic manner. While there is probably little gold likely to be extracted from seawater, we do know that of the vast geothermal resource, the small part that can practicably be used will be important. Calculations of the total resource within defined parameters do serve a useful purpose in furthering our understanding of the enormous base of energy with which we are dealing. But these

estimates should never be confused with what may be realistically obtainable. D. E. White* estimates the resource in the top ten kilometers of the earth at 3×10^{26} calories. Under the United States alone, his estimate indicates 6×10^{24} calories. This is many orders of magnitude above what can be considered as a recoverable resource base.

Our real challenge, then, is to learn more about the nature of geothermal energy, to find where it is accessible, and then to learn how to develop and use it at reasonable cost. Only then can this resource be mined in a competitive, commercial manner.

B. Practical Resources

Making estimates of the practical or economically recoverable geothermal resources is a relatively easy task. Supporting those estimates with solid data and proven technology is not only infinitely more difficult but actually impossible because supporting data and technology are non-existent. Consequently, we find estimates all too often severely shaded by the analyst's individual optimism or pessimism. This first table shows a few of the many estimates that have been made. The table is presented here not to define the size of the recoverable resource, but rather to illustrate the very broad range of thinking which reflects the uncertainty attached to this fledgling industry. Most estimates have some rational basis, and it is generally unfair to criticize them out of hand. Others, unfortunately, have been designed to promote geothermal energy as a kind of exotic and glamorous source, and to thrust aside the need for continuing development of

* Geothermal Energy; edited by Kruger and Otte

fossil-fueled and nuclear energy production. Those engaged in drilling and utilization tend to arrive at conservative estimates based more on what is proven than what might be projected.

The California Geysers development is the most explored and developed geothermal area in the world. Information on the field has been accumulating since the early 1920's and especially since significant utilization began in 1960. Periodic reassessments of the resource have increased confidence and commitment so that over 900 megawatts are scheduled to be in operation by 1979. But even in this well-studied area the size of the resource is uncertain. Some wells drilled in the Known Geothermal Resource Area (KGRA) have failed to produce steam while other wells to be drilled outside the defined KGRA are almost sure to produce steam. It is clear that there is more energy that can be developed but that the ultimate size of the resource is not known. It can best be defined through a careful, evolutionary type drilling program.

From the information now available, it appears highly unlikely that the amount of geothermal energy will ever supply more than 10 percent of the nation's needs. Indeed, it is doubtful that, even with the several attractive geothermal developmental areas in California, geothermally-produced electricity will ever exceed 10 percent of the State's requirements. This does not indicate, by any means, that geothermal energy is an unimportant source. The future electrical energy growth rate in California alone is very large and a 10 percent share is likewise substantial.

TABLE 1
PARTIAL TABULATION OF ESTIMATES OF GEOTHERMAL
POTENTIAL AT THE CALIFORNIA GEYSERS AND
IN THE UNITED STATES

<u>Megawatts of Electrical Generation</u>	<u>Year Corresponding to the Level of Generation</u>	<u>Attributed To</u>	<u>Publication</u>	<u>Date of Publication</u>	<u>Comments</u>
<u>California Geysers - Known Geothermal Resources Area</u>					
2,000	Ultimate	J.P. Finney*	Public Utilities Fortnightly	1/31/74	*Project Engineer for Pacific Gas & Electric Co. Geysers development. Est- imate based primarily upon the size of resource exposed by completed drill- ing, with little extrapola- tion for unproven areas.
4,800	Ultimate	Geothermal Re- sources Board of California	Economic Potential of Geothermal Re- sources in Calif.	1/71	
25,000	Ultimate	Dr. R.W. Rex	USAEC Hearing, Dia- blo Canyon Nuclear Units, Dockets Nos. 50-275; 323	5/19/72	Corresponds to the produc- tion of the entire geother- mal area at same rate per acre as the presently dev- eloped area.
<u>United States</u>					
3,000 to 19,000	1985	National Pet- roleum Council	U.S. Energy Outlook	12/72	Range depends on price, technological development, and the degree of institu- tional and ecological im- pediment
20,000 to 30,000	1985	Interagency Panel for Geothermal Energy Research	Report to Office of Management & Budget	6/10/74	

<u>Megawatts of Electrical Generation</u>	<u>Corresponding to the Level of Generation</u>	<u>Attributed To</u>	<u>Publication</u>	<u>Date of Publication</u>	<u>Comments</u>
132,000	1985	Walter J. Hickel	Geothermal Energy, from estimates re- ported at the 1972 Geothermal Resources Conference	1972	Assumes development of hydrothermal, geopressured, hot rock, and magma systems
5,000	2000	Dr. Chauncey Starr**	Energy and Power Scientific American	9/71	**President of the Electric Power Research Institute
200,000	2000	Interagency Panel for Geothermal Energy Research	Report to Office of Management & Budget	6/10/74	
395,000	2000	Walter J. Hickel	Geothermal Energy, from estimates re- ported at the 1972 Geothermal Resources Conference	1972	Assumes development of hy- drothermal geopressured, hot rock, and magna systems
2,850***	Ultimate	D.E. White	Geothermal Energy; Ed- ited by Kruger and Otte	1973	Includes proved, probable, reserves at 1972 prices and technology
9,500 to 19,000***	Ultimate	D.E. White	Geothermal Energy; Ed- ited by Kruger and Otte	1973	Hydrothermal systems only; Assumes 50% increase in price
4,750 to 190,000,000***	Ultimate	R.W. Rex and D.J. Howell	Geothermal Energy; Ed- ited by Kruger and Otte	1973	High figure based on undis- covered hot rock systems at much higher prices than present

*** Original estimates were given in the form of megawatt-centuries. For comparison purposes, they have been converted to megawatts of installation based upon a 30-year life of plant operating at 70% capacity factor.

II. RESERVES PRESENTLY AVAILABLE AT GIVEN PRICES

A. Status of Geothermal Power Use

For centuries, man has used natural hot waters and steam for heating, bathing and therapeutic purposes. In a few areas, wells have been drilled to produce steam or hot water for space and process heating and electric power production. In Iceland, geothermal energy is used by about 100,000 people for residential heating. In New Zealand, a pulp and lumber facility uses it for process heating. In a number of places in Europe and Asia, geothermal energy is used to heat greenhouses for year-round crop production. In Klamath Falls, Oregon, and in Boise, Idaho, it has long been used for space heating in several hundred buildings.

The most dynamic use, however, is conversion of geothermal energy into electrical form. In that form, it can be moved great distances and put to innumerable uses. This next table summarizes the world development of geothermal electric generation. The summary shows that geothermal power, however important it may be locally, still represents only a very small percentage of the total electric power generation of any nation.

The first production of electric power from natural steam occurred at Lardarello, Italy, in 1904. This area now produces 365 megawatts from a dry-steam or vapor-dominated geothermal reservoir. The Wairakei and Kawerau fields of New Zealand are liquid-dominated resources from which 202 megawatts have been developed using steam flashed from hot water wells. In Northern Mexico, the 75 megawatt Cerro Prieto plant was recently commissioned for use of steam flashed from hot brine having about the same salinity as seawater. Geothermal power instal-

lations in Russia, Japan and Iceland are relatively small.

The most rapidly expanding development is at The Geysers field in California. (This is not truly a geyser, but rather a fumarole area.) Technology for utilization of dry steam at this location has been reported upon in considerable detail.

Those who have worked with geothermal resources recognize fully that geothermal steam, hot waters and brines represent valuable and important resources for the future development of electrical power, as well as other potential uses. However, these resources must be developed in a rational and practical manner.

B. The Geysers

In the 1920's, a number of test steam wells were drilled in the Imperial Valley and at The Geysers in California. However, relatively inexpensive hydroelectric power was then abundant and the potential for generating power from geothermal sources was not economically attractive. Furthermore, there also were some unknown, untested problems associated with the use of geothermal steam. The resource was in a remote area which would not justify expensive transmission installations for the relatively small size of units that would have been practical in that era. Nevertheless, developers continued to pursue its possibilities.

In the late 1950s, following the commendable drilling and developmental effort at The Geysers by the pioneering Magma and Thermal Power Companies, Pacific Gas and Electric Company became interested in testing the feasibility of geothermal electric generation. The resource appeared promising, and contracts between the utility and the steam

TABLE 2

WORLDWIDE STATUS OF GEOTHERMAL POWER DEVELOPMENTS

Country	Approximate 1973 Geothermal Electric Capacity (Megawatts)*	Reservoir Fluid*	Power Cycle F, Flashed Steam D, Dry Steam B, Binary	1972 Total Electric Installation Megawatts**	Geothermal As a Percent of Total Electric Installation
Iceland					
Narafjall	3	Hot Water	F	400	0.76
Italy					
Lardarello	365	Steam	D		
Monte Amiata	25	Steam	D		
Total	390			36,000	1.1
Japan					
Matsukawa	20	Steam	D		
Otake	13	Hot Water	F		
Total	33			76,000	0.043
Mexico					
Cerro Prieto	75	Hot Water	F	8,000	0.95
New Zealand					
Wairakei	192****	Hot Water	F		
Kawerau	10	Hot Water	F		
Total	202			4,000	4.15
U.S.A.					
Geysers	396***	Dry Steam	D	419,000***	0.095
U.S.S.R.					
Pauzhetsk	5	Hot Water	F		
Paratunka	1		B		
Total	6			175,000	0.003
Total World	1,105				

* Geothermal Energy, by P. Kruger and C. Otte, 1973

** UN Statistical Yearbook, 1973

*** 1973 Figures

**** Wairakei Geothermal Project; New Zealand Ministry of Works, March 1972

developers were signed to cover a program of continuing installation of geothermal electric generation. Expansion was geared to further exploration and successful production of additional steam. These contracts led to the first commercial production of electricity from geothermal energy in the Western hemisphere. This 1960 event initiated an ever-increasing interest in the future potential of geothermal resources.

The first small unit (11 megawatts) provided the basic economic and technological data for using this local dry steam resource. As confidence grew, the size of the units also grew. The largest now in operation is 106 megawatts and the largest planned is 135 megawatts. With the installation of the eleventh unit in 1975, The Geysers project became the largest geothermal power installation in the world with an output of 502 megawatts. Thus, in only 15 years, the use of geothermal energy for electric power production in Northern California has progressed from the status of an R&D project to that of an important supplemental power source.

Four additional power units are scheduled to become operational in the years through 1979. This will raise the output of The Geysers project--still the only commercial geothermal-electric development in the United States--to more than 900 megawatts. Beyond that, about 110 megawatts of additional capacity are planned for installation each year through 1985. Annual reappraisals of the potential of the steam field probably will justify continuing the development many years beyond 1985. Addition of new generation at a rate greater than 100 megawatts a year is possible if the steam suppliers accelerate their resource development program.

Because of the relatively low pressure and temperature of the natural steam, the physical size of equipment per megawatt of generation is relatively large. The secondary-class access roads into the mountainous area impose limits on the weight and dimension of equipment which can be transported to the steam field. Fortunately, the economic unit size and road limitations are closely compatible. Relatively small units provide a reasonable economic balance between the cost of delivering steam from distant wells and the lower cost per megawatt of installing larger generating units.

C. The Economics of Geothermal Power

There is little information upon which to base a price-availability relationship for geothermal energy except from The Geysers development. Obviously, the cost of geothermal power will depend to a considerable degree upon the quality of the energy. Ideally, it would be in the form of dry steam under very high temperature and very high pressure, but nature has not offered it in this form. Developers willing to accept what nature does offer see no insurmountable technological problems with using superheated waters or low-quality steam. It must be recognized, however, that The Geysers area is unique. Development of the field has been singularly successful because the steam was dry and the technology for utilization was available at the time the development began. The first unit installed at The Geysers applied the turbine and generator technology of the early 1920's through the installation of used equipment of 1923 vintage which was moved from a retired, in-operative plant. Furthermore, much of the early steam was found relatively near the surface and was developed at relatively low cost. The

technology and economics of The Geysers development must never be used as a measure for evaluating other locations having even modestly different characteristics.

III. RESERVES AVAILABLE WITH GIVEN ENVIRONMENTAL CONSTRAINTS AND THE EFFECT OF RELAXATION OF THOSE RESTRAINTS

Geothermal energy generally enjoys the reputation of being environmentally pure. Many people who oppose construction of fossil or nuclear generating projects, therefore, urge geothermal generation as the ideal environmental alternative.

Unfortunately, geothermal power is not without environmental problems. On the positive side, we can note that these problems seem manageable, even though costly. So long as environmental constraints are imposed within reasonable and responsible bounds, development can proceed.

Most natural hydro-thermal systems contain non-condensable gases in varying amounts. Hydrogen sulfide is only a small portion of such gases but is readily detected through its characteristic rotten-egg odor. If the geothermal steam development is located in a relatively unpopulated area, the presence of hydrogen sulfide may, in terms of environmental effect, be quite unimportant. However, regulatory limits seldom recognize the location or unique circumstances and can be unrealistically restrictive. In addition to natural release of hydrogen sulfide through fumaroles at The Geysers project, some hydrogen sulfide is released to the atmosphere from the plant condenser vents and cooling towers. To comply with the applicable air quality standards, a major research effort has developed a process for abating the release of hydrogen sulfide gas from the power units.

The process results in the production of elemental sulfur in the form of a wet sludge having no commercial value. This sludge is disposed of in a controlled land fill.

Initially, at The Geysers, the unevaporated condensate from the power cycle was released to the natural drainage channels and no problems were detected. However, as development grew, the ammonia content and the quantity of effluent increased to the point where there was potential for an adverse effect upon the local fish life. Further, small concentrations of boron in the condensate created concern because it was known that boron in small quantities could be harmful to certain types of vegetation. Both the ammonia and boron questions were resolved by reinjecting the unevaporated condensate into the underlying steam-producing formations, where it is believed to be reheated by the hot rock and flashed to steam, thereby extending the productivity of the reservoir. For development in other areas where brines or even relatively pure waters are to be released in drainage channels or into bays or the ocean, the impact of those liquids upon the aquatic environment must be considered carefully.

Characteristically, geothermal resources are found in areas of seismic activity. One of the techniques for locating potential geothermal resources is through measurement of micro-earthquakes. Although there have been some questions raised about the possibility of wells being offset in a seismic break, the probability is so remote as to be ignored and structural designs of surface facilities to resist earthquakes are quite manageable.

Land subsidence has been reported at the Wairakei project in New Zealand and the Cerro Prieto project in Northern Mexico. It is be-

lieved that this problem will generally be associated with withdrawal of hot water from geothermal reservoirs, particularly in sedimentary formations. In rock formations such as those at The Geysers, subsidence is not expected.

Geothermal projects have been affected by increasing concern over possible effects on the environment. Regulatory agencies now require submittal of extensive environmental statements. Unfortunately, as presently implemented these requirements are imposed upon each new increment to the development and because the geothermal generating units have relatively small capacity, new units are added at fairly frequent intervals with the associated requirement for new environmental reports. In California, it is presently necessary to prepare detailed environmental data statements for each addition, even though the individual geothermal area may have been discussed in detail in several earlier data statements. The burden and cost to the utility of preparing statements may be manageable, but the cost and delay are compounded immensely because regulatory bodies must prepare their own environmental statements after reviewing those of the steam developer and the utility. Acceptance of a single environmental report for each specific geothermal resource area would be helpful. The value of such a concept has been recognized at the state level in California and currently there are legislative efforts to streamline the regulatory review and advance the rate of geothermal development.

In some areas, land use compatibility of geothermal development could be a problem. Construction and operation of geothermal plants are basically industrial activities. Roads must be constructed to individual well sites, wells must be drilled, and piping systems must

be installed to carry the steam or hot water to the generating or process plants. The plants themselves and associated electric transmission lines must be constructed. Even at The Geysers, located in an area having relatively few other uses, matters of land use compatibility must be addressed and resolved.

Aside from the possibility of institutional restraints, it is believed that the environmental problems of geothermal development in most places can be solved through applied technology. There is no reason to believe geothermal energy will be attended by any more serious problems than energy from fossil-fuel sources. With a growing realization of the importance of conservation and early development of domestic energy resources, there is every reason to develop and impose environmental constraints in a reasonable manner. If, however, additional layers of "unnecessary" environmental requirements are imposed, costs will get excessive and projects cancelled due to the problem of meeting such requirements. In our striving towards energy self-sufficiency, it would appear counter-productive to preclude the use of this valuable natural resource by unnecessary or punitive regulatory requirements.

IV. STATE OF THE ART

A. The Origin of Geothermal Energy

A widespread view on the source of geothermal heat is that it arises largely from the decay of radioactive material. In addition, exothermic chemical reactions and frictional sources within the earth undoubtedly contribute some of the heat. This heat is transmitted to the earth's surface everywhere. In most regions, however, it is too

diffuse to be noticed. In other regions, it is found in dramatic volcanic lava flows and in geyser displays such as "Old Faithful" in Yellowstone Park.

In some regions of recent volcanism, generally associated with tectonic plate boundaries, large amounts of heat are contained in solidified magma at relatively shallow depths. In some of these areas, surface water percolates into the formations. When the water comes into contact with the hot rock, convective cells are formed causing hot water or steam to rise toward the surface. If this water penetrates the surface, geysers, hot springs or fumaroles appear. In the United States, such areas are found predominantly in the West.

It is convenient to separate geothermal resources into four major types:

1. Hydro-thermal systems; of which there are three sub-types:
 - a. Dry steam (vapor-dominated) systems
 - b. Hot water (liquid-dominated) systems, mildly mineralized
 - c. Hot water (liquid-dominated) systems, highly mineralized
2. Geopressure systems
3. Hot, dry rock systems; of which there are two sub-types:
 - a. Hot, dry rock without added heat
 - b. Hot, dry rock with nuclear heat added
4. Magma

Let us now look at each of these types.

1. Hydro-thermal systems

The systems which produce steam, either directly from vapor-dominated fields or flashed from liquid-dominated fields, provide all of the geothermal resources used for electric power generation today.

Proven technology now exists for these systems and they are, therefore, the easiest to develop.

a. Dry steam (vapor-dominated) sub-type

The Geysers steam field in the United States and the Lardarello development in Italy are the major fields which produce dry steam for electric generation. Power installations using dry steam at Monte Amiata, Italy and Matsukawa, Japan, are small. The potential for added development at these locations is not known. White* suggests that the higher-temperature vapor-dominated sub-types such as Lardarello and The Geysers probably require a discharge area with recognizable surface manifestations and, therefore, we probably are already aware of all such systems. Other vapor-dominated systems at relatively low temperatures such as that at Monte Amiata will be harder to find because surface manifestations will not be readily observed. Fields like Lardarello and The Geysers are commercially attractive, but it must always be kept in mind that the economics and technology for their utilization cannot be transferred directly to the liquid-dominated or other types of geothermal resources.

b. Hot water (liquid-dominated) systems, mildly mineralized

Because liquid-dominated systems are much more abundant, techniques for utilizing this source of heat are currently receiving increasing attention. Much of the exploration throughout the Western United States in recent years has located hot water sources. The Wairakei and Kawerau installations in New Zealand, the Cerro Prieto plant just south of the United States border in Mexico, and an instal-

* Geothermal Energy; edited by Kruger and Otte

lation in Japan all utilize heat from hot water systems by allowing the superheated water to flash to steam. While this process of obtaining steam for power production is simple, it does leave large quantities of residual water, sometimes of high mineral content, that must be disposed of.

An alternative method for extracting heat from hot water or brines is through the use of heat exchangers. The Magma Power Company has been particularly active in developing and promoting its Magmax binary system, in which even fairly low-temperature hot water or hot brine from liquid-dominated systems can be circulated through a heat exchanger and transferred to an organic liquid such as isobutane or freon. Such liquids have low boiling points (14°F at one atmosphere for isobutane) and can be converted into gaseous form, just as we convert water to steam. The expanding gas then acts as the driving medium to extract much electrical energy from the more abundant but relatively low-grade geothermal heat sources. The very small binary system installed on the Kamchatka peninsula of Russia, with freon acting as the working fluid, seems too small for commercial extrapolation. Commercial development of the more abundant, low-grade, liquid-dominated heat sources, therefore, awaits demonstrated heat exchange technology and demonstrated economic feasibility.

In most cases, it is contemplated that the "spent" hot water from binary systems would be reinjected into wells to avoid environmental problems stemming from surface disposal.

c. Hot water (liquid-dominated) systems, highly mineralized

A notable example of a highly mineralized water system is that in the Imperial Valley of California near the Mexican border.

Tremendous quantities of heat are found in the hot water underlying large areas of the Valley. Numerous wells have been drilled and the potential of the area has been under study for many years by the University of California at Riverside, by steam developers which include some of the oil companies, and by Southern California utilities.

A major effort is underway to use the heat for electrical generation and for extracting potable water. Most of the problems in extracting the heat relate to the very high mineral content of the hot water, as much as 10 times the mineral content of seawater in some areas. Special technology will have to be applied to overcome problems of corrosion and scaling in plant equipment, particularly heat transfer equipment. The best prospect for using this heat to generate electricity is thought to be through the use of a binary system similar to that being investigated by the Magma Company. An experimental module of such a system has been installed through the joint efforts of the Magma Power Company and San Diego Gas and Electric Company. Some interest has been exhibited in obtaining valuable chemicals from the brines, but it is clear that all of the chemicals could not be removed economically. Reinjection of "spent" brines into wells appears to be the only environmentally acceptable method of disposal for this area.

2. Geopressure systems

A rather fascinating potential resource exists along the Gulf Coast in geopressure systems. While exploring for oil, drillers have encountered "geopressure" areas between the Continental Shelf and about 100 miles inland in an area extending from Texas to Florida. These zones are believed to result from the entrapment of water along

these geologic faults. Subsequent subsidence and compaction of material above the faults has occurred until the entrapped water itself has become the load-bearing substance creating a "geopressure" reservoir. In some of these reservoirs that water is quite hot, it has an extremely high-flowing wellhead pressure, and contains up to 30 cubic feet of dissolved methane gas per barrel of water.

These systems have potentially great energy capability because of three physical characteristics: (i) the water is at such pressure that it could be run through hydraulic turbines to extract energy; (ii) there is enough heat in the water that energy could be extracted through a binary-cycle system; and (iii) very importantly, the methane gas could be extracted from the fluid and its energy utilized.

C. S. Mathews* of Shell Oil Company has stated: "The problem of locating large, hot, highly productive geopressured reservoirs will be a very difficult exploration problem. Its solution will require both skill and luck." A. T. Maasberg and O. Osborn* of the Dow Chemical Company have made this succinct assessment: "The economics of power production from Gulf Coast geopressured waters appear very attractive, and the potential returns are high. However, the risk is also high, and the development costs will be large."

3. Hot, dry rock systems

The hot, dry rock systems offer theoretically the greatest amount of potential energy; but to date, they have not been exploited beyond preliminary research. Hot rock underlies all of the earth's surface. However, due to economic and physical limits for deep drilling, it is

* Hearing before Committee of Science and Astronautics, Subcommittee on Energy, H.R. 11212, The Geothermal Energy Research, Development and Commercial Demonstration Act of 1973.

only where the higher temperatures are relatively close to the surface that we might expect to extract their energy.

Currently, the Subterrene draws considerable interest because it offers the possibility of overcoming some of the depth limitations. The Subterrene is a system invented and patented by the scientists at the Los Alamos Scientific Laboratory for making vertical or horizontal holes in the earth by melting rock and soils. The penetrator which acts as the drill bit would be heated either electrically or with a specially-designed nuclear fission reactor. Practical development of the Subterrene would provide substantial advantages over conventional methods of deep drilling not only for geothermal energy exploitation but for other purposes as well.

a. Hot, dry rock without added heat

An over-simplification of the concept for extracting heat from hot, dry rock requires two or more holes to be drilled into a high-temperature rock system. In the absence of natural permeability, hydro-fracturing processes would be used to open the formations between holes. Water, or perhaps another fluid, would then be injected from the surface into one or more of the holes. The fluid would circulate through the reservoir and return to the surface through the other holes at an elevated temperature, either as a liquid or as steam. The fluid in this manner would "mine" the heat of the dry rock system. Drilling and experiments for utilizing this resource are underway in Montana and New Mexico.

b. Hot, dry rock with nuclear heat added

Battelle-Northwest Laboratory, working with the American Oil Shale Company and others, in 1971 prepared a comprehensive study of a

potential utilization of hot, dry rock. It was proposed to drill into hot, dry rock and create a permeable pocket at depth through an atomic detonation. The atomic detonation would add heat to that naturally present. A water injection hole and a separate heat extraction hole would then be drilled into the permeable pocket. The combination of both heat sources was indicated as necessary to achieving overall economic feasibility.

There are two readily-apparent problems associated with this type of geothermal development: (i) The detonations would be required at fairly frequent intervals in order to maintain enough energy for continued operation of a power plant. Detonations would require hardening the plant against shocks or designing the plant so that it could be moved temporarily away from the area of detonation in a canal or on rails. While technologically possible, the complications of dealing with the explosive shocks seriously erode the economics. (ii) Although the proposed procedure responsibly considered all the features required to make it radiologically safe, the concept is still hampered by the public's reluctance to accept atomic detonations in any form.

While this plow-share type project has not been abandoned, it is definitely on the back burner.

4. Magma

Solidified magma might be tapped as an energy source through the hot, dry rock concepts described under 3 above. Tapping the energy of molten magma or lava systems would require totally different technology. Such molten systems do contain immense amounts of energy in spectacularly evident form, but these are found only in a few places

in the world and on a somewhat unreliable, intermittent basis. In any event, such systems may defy practicable technology to harness the energy.

V. RESEARCH AND DEVELOPMENT GOALS

A. Major Problems and Their Solutions

Once a geothermal resource is brought to the earth's surface, most of the technology already developed for the utilization of other kinds of heat sources will be applicable to the conversion of geothermal energy for man's use. The technology for the use of dry steam such as that found at The Geysers is basically the same technology that has been used for decades in electrical generation. Nature has merely provided the boiler and the steam is run through low-pressure, low-temperature turbines of a design not too different from that of 50 or more years ago. Because of the chemical content of the steam at The Geysers project, there are turbine blade deposits which require additional maintenance. Surfaces in contact with the steam or condensate require special treatment and certain sensitive electrical gear is confined to special rooms away from the corrosive effects of hydrogen sulfide. Rock and dust that get past the centrifugal separators and screens can create serious turbine blade problems. However, when one considers that the steam used in fossil or nuclear units is extremely pure, it is remarkable that these geothermal units operate at and above a 70% capacity factor. Most of the design and operational problems are now well understood and efforts are being made to push output of the project substantially above 70% capacity factor.

The more hostile forms of geothermal resources such as heavy brines will require use of special materials. Scaling of conduits and heat

exchangers through which the brines will move may be a serious problem.

Certainly, there needs to be a demonstration of the workability and reliability of heat exchangers and of energy conversion machinery to be used with working fluids such as isobutane and freon.

The only long-term experience with reinjection of geothermal effluents is at The Geysers. Similar experience will be needed in other areas.

Probably the most pressing technical problems associated with accelerating the expansion of geothermal energy use lie in the arms of resource exploration, assessment and development. Too little is presently known about the location and potential of this resource, assessment techniques are limited, and less expensive ways of drilling for and producing the resources are needed. We must learn much more about all these subjects.

Also, we must clear away certain non-technical problems which tend to inhibit geothermal development:

1. Institutional Problems

Sixty percent of the identified potential geothermal property is on federal land. Bids totaling about \$6.8 million were opened in January of 1974 for geothermal leases of 53,000 acres of federal land in California. This implementation of the Geothermal Leasing Act of 1970 was long overdue and further, leasing should be expedited to stimulate development of this nation's geothermal reserves. The ownership of steam on large acreages in the West where mineral rights are reserved to the federal government is still being argued in the federal courts. Adjudication of these questions should be accelerated.

2. Scarcity of Tubular Goods

Limited supply of tubular goods such as well casing has been reported recently as a limiting factor in the development of oil and gas resources. Competition for supplies of this kind poses a serious problem for a large-scale geothermal development program. Expansion of mill capacity for producing these goods should be encouraged.

3. Availability of Drilling Rigs

Drilling rigs are specialized, expensive, large pieces of equipment which take a long time to manufacture and put into operation. It would take about half of all the rotary drill rigs in the United States today working until the end of this century to develop the resource suggested in the Hickel report. Hickel, you may recall from the first table I presented today, estimated that the total U.S. geothermal resource was 132,000 MW and that this amount of generation could be developed by 1985. And this assumes that every well would be successful and that the wells would produce for nearly a century without the necessity for re-drilling or developing fill-in wells. Advancing the rate of development of geothermal resources, therefore, will have to be accompanied by a significant increase in availability of drill rigs.

4. Availability of Electrical Generating Equipment

There is no question of the manufacturers' ability to produce equipment for the utilization of geothermal steam for generation of electricity. There is doubt, however, how far the geothermal electric industry must be developed before manufacturers will see sufficient potential profit to commit the necessary plant for manufacture of the specialized equipment at other than custom-made prices. Manufacturers

need a large enough assured base to justify entering the market competitively and economically. Since The Geysers-type equipment will not be usable at most other areas which call for different technology, convincing suppliers to dedicate their resources to making standardized equipment for other types of geothermal energy may be a slow process.

5. Availability of Capital

The average steam well at The Geysers project currently costs somewhere between one and two-thirds million dollars to complete. The cost of the electric generation and associated facilities is estimated to be about three times the cost of wells and other production facilities. If resources of the expansive magnitude suggested by some should be developed, we would be looking for about \$4 billion per year. It can only be with proven economics and an assured supply of heat that an industry would ever make such an enormous financial commitment.

B. Necessary R&D Programs Relating to Electrical Generation

There are also major technological areas where R&D seems to require concerted effort. Some were mentioned earlier.

- 1) Exploration technology
- 2) Deep, hot drilling technology
- 3) Geothermal reservoir engineering
- 4) Material corrosion and heat transfer scaling investigations
- 5) Organic fluid power machinery

Locating oil reserves is a reasonably advanced technology, developed over many years through identification of specific types of geological structures. This is not true with geothermal resources. Generally, we start from surface indications such as hot springs or fumaroles. Heat-flow studies from relatively shallow holes can pro-

vide some information. The final test, of course, is in drilling. New and more efficient exploration technology should be a high priority R&D goal.

Present techniques for deep drilling in geothermal areas are those developed in the gas and oil industry. If some of the deep hot rock formations are to be reached and utilized, new methods will be needed. The Subterrene, described earlier, offers one possibility.

After a geothermal resource is located, drilled and tested, it needs careful assessment. In the case of vapor-dominated systems, techniques similar to those used for assessing natural gas reservoirs can be utilized. If, as some believe to be the case, vapor-dominated systems are recharged from liquid reservoirs at great depth, the resource is much greater than would exist with a vapor reservoir alone. Wells about 9,000 feet deep at the California Geysers have not reached an interface. More would be known about the nature of the reservoir if such an interface could be found, and suggestions have been made for drilling holes on the order of 20,000 feet deep to answer this question. Such a hole would be very expensive and evaluation of what benefits might be obtained from such an effort is still under study.

To the extent that utilization technology still has gaps, research effort should be made on the problems of material corrosion and heat-transfer surface scaling. The gaps are fairly well closed in utilization of the dry steam at The Geysers where research has been completed or is underway, but the gaps are wider for utilization of heat from liquid-dominated systems, especially those having high mineral content. Current research programs to investigate the binary cycle

using organic fluid power machinery should be accelerated.

The fact that some research has been undertaken does not mean that parallel research efforts using different techniques should not be started. Both new and backup research programs leading to development of new economic techniques are needed.

VI. MAXIMUM ACCELERATED APPROACH

The rate at which geothermal development occurs will not be controlled by a predetermination of how fast it should proceed, but rather by constraints which now exist and which may build up around it. Such constraints will be both technological and institutional but basically the rate of development will be controlled by the confidence that grows with success in various aspects of research and discovery and then, finally, through the test of cold economic realities of investment and operation. Electric utilities, which are prospectively the major users of geothermal resources, have been notably cautious in shouldering large, speculative investments because of the regulated nature of their business. The rate of development of such an infant industry as geothermal should, in a utility view, be continued on an evolutionary basis to match the proven resources rather than presuming that the resource is available and attempting to match the presumption. The rate of development certainly can be accelerated but the whole concept would be seriously harmed if the rate of commitment to development should overrun the availability of the resource and usable technology.

VII. SUPPLY OF GEOTHERMAL ENERGY PROJECTED TO 1980, 1990, 2000

Many factions want to increase the production of geothermal energy -- including environmentalists, drillers and producers of steam, electric utilities, research organizations, geophysicists, geologists, and some politicians who properly understand that the energy crisis is real and long-term. With this support, geothermal energy is likely to be developed to its maximum economic capability. Geothermal energy needs enthusiastic voices to keep its development moving, but that enthusiasm should never lead to irresponsible suggestions, as have been made in the past, that everything should stop while we wait for a full geothermal economy to arrive. The nation should not overreact to geothermal energy's appeal and follow a course of wasting another important resource -- our nation's dollars.

While the potential for using geothermal heat in electric generation is quite important, extrapolations of the present, meager information on this resource should not overshadow the need for continuing development of other sources of electrical generation. While pressing very hard for development of geothermal energy as a proper part of the mix of world energy resources, we must continue to use the full range of energy sources available now.

VIII. USES AND BENEFITS OF GEOTHERMAL TECHNOLOGY

Two centuries ago, the industrial revolution began with the use of fossil fuels. First coal and then oil and gas served man's ever-increasing need for energy. In the period to the end of this century, nuclear energy holds promise of becoming a dominant energy source. In fact, it will be essential if we are to meet the nation's

need for electric power. Coal will also be an important heat source. In this period, geothermal energy can be expected to become an increasingly important supplemental energy source in a number of regions in the West; but it is now difficult to conceive of geothermal power providing 10 percent of the electric energy needs of the nation or even of one of the more active geothermal areas, California. In some areas, production of potable water is possible through the use of geothermal energy, and in those areas where highly-saline geothermal waters are available, raw materials for the chemical industry could be important.

Encouragement is needed for advancement of the technology necessary to assess and develop this resource, wherever it can be found, so that the economic sources will be utilized as rapidly as possible.

SOLAR ENERGY

**By
DAN HALACY**

**Assistant to Senator Paul Fannin
5429 Federal Building
230 North First Avenue
Phoenix, Arizona 85025**

SOLAR ENERGY

It's a real pleasure to be here this morning. I bring you greetings, first of all, from Senator Paul Fannin who I hope you all know is the energy expert in the Interior Committee. The Senator, before getting into politics and government, was involved in the energy business himself so he is knowledgeable in the whole spectrum of energy: petroleum, gas, coal and nuclear. He knows that we have to use everything we have. We have to improve these sources but at the same time he feels we had better start bringing on our alternative sources. In 1973, he authored the Geothermal Energy Act.

I'm sure you know he's also been very active in solar energy for a long time. Back in 1962, the Senator had the privilege of dedicating the solar still down at Puerto Penasco, Mexico. That's the facility that Carl Hodges and others at the University of Arizona put together. From it came the hydroponic farming which has now spread around the world. We'll see some slides of that later on.

I joined the Senator's staff in January of 1975 and our mission was actually twofold: First, to bring the Solar Institute to the State of Arizona. At the moment it's looking very good so keep your fingers crossed for us that we'll get the Institute. Second was to help develop solar energy in the State of Arizona. Part of that task has been traveling around the state speaking to groups, but it's rare that I have a chance to talk to people like you. Generally I talk to fifty people

and hope to make 10 converts but here I know that if some of you by now aren't really solar converts and I make one, you'll go back and make 50-100, potentially 1,000. I'm delighted to talk to this kind of an audience.

Mrs. Warner spent a good deal of time yesterday talking about the solar budget compared with other budgets. I should pass on to you that Senator Fannin is one of those involved in raising the budget for 1977 from its original one hundred and some million dollars to something close to two hundred sixty million dollars. So, there will be more money for solar next year. Incidentally, Dr. Charles Backus, who will follow me this morning, was one of those who went back to Washington and testified at the hearings that more money could be spent very usefully on solar energy.

I'm delighted that ERDA has seen fit to fund this particular meeting. I'm delighted with the subtitle, especially the word "orientation". Because orientation, I'm sure you recall, means an arrangement with relation to the rising sun. Fittingly, this morning's part of the orientation will be solar energy. I'll try to stick to an overview of solar energy; not from the scientific or technical standpoint but from that of the educated and interested layman.

It's really a tonic to be standing here talking about solar energy as a thing in being. I got started a long time ago before most people did, before most people knew solar energy had these great potentials. Unfortunately, most of my friends and others I've talked with in the years between felt that I was suffering from sunstroke when I talked about solar energy powering the world. But I know that you are going to believe these things I'll tell you. It's going to help to show slides

that document them. I apologize for perhaps seeming too basic but I don't really know any other way to tackle it. This will be a very general overview of solar energy, and some of the things that you as educators can do...some of the tools that are available.

Slide #1, which I'm sure came from Arizona Public Service, heralds the age of solar energy. Of course, this solar age that we're in right now is sort of like the energy crises that we've had. It's not the first. There have been several solar ages, and one was ushered in by Archimedes, and I'm sure you're familiar with this old story which for years was considered a legend or a myth.

Slide #2, shows Syracuse, the harbor at Syracuse, and Archimedes there in the toga happily setting fire to the sails of the attacking Roman vessels.

Many historians have dismissed this as something that just couldn't have happened. But others think it's a fact and recently some scientists and engineers in Italy reconstructed the scene; actually built a mock-up of a wooden ship and then lined the shores not with mirrors such as we see in this artist's conception but with a number of gentlemen posing as soldiers and each holding a polished piece of metal which would approximate a shield. They were all instructed on how to aim these things at the ships and it's not too high a technology. If you've ever used signal mirrors, it's not that big a trick. Lo and behold, almost instantaneously the sails of this model ship caught fire. This was reported in Time magazine not long ago so I'm convinced that the thing actually happened in the year 214 B.C. Happily, this is the only instance I've ever come across of solar energy used as a military weapon. I'm sure our military planners will again find ways of doing it but I hope that takes them some time.

There was a long gap--not a great deal came of Archimedes' great solar engineering feat. I guess most people just didn't believe it. So we're now up to the time of the French revolution or shortly before. Slide #3 is of Lavoisier, the French scientist. I'm sure you're familiar with his work; he did many good things. His solar experiments are not as well known as his other experiments, but this was a fairly sophisticated solar furnace--a two-lens affair. The lens were interesting; they're sizeable as you can see, and generated temperatures approaching 2000°C which is quite useful in a science lab. They were made of glass in two halves, curved pieces, somehow cemented together. Normally water would be put between the halves but Lavoisier used wine.

Unfortunately, he was a victim of the Revolution. The French radicals decided they had no further need for scientists and Lavoisier lost his head. Solar energy was slowed down until the next solar age came along.

Slide #4 was just about a century ago at an exhibition in Paris. Maybe some of you have seen this picture before. It's not a photograph but a pretty accurate drawing, I'm sure. This is a small solar engine, perhaps one horsepower or less. The umbrella-shaped affair is a mirror concentrator running a boiler which ran an engine, and in turn a printing press. The printing press turned out a little paper for this exposition called "The Solar Journal." Clear documentation nearly a century ago, this was 1878 as I recall, of the ability of solar energy to produce power.

Another application of solar energy was completely different; a solar still. Slide #5 had wide circulation. Perhaps you're familiar with it. It was built in Chile, a place called Las Salinas, so called because only brackish water was available. This was a mine and there was no fresh water except that brought in on the backs of pack animals. So they built this

still which produced 6000 gallons of fresh water a day. This was in 1872. I'm happy to report that an American engineer designed and constructed the project. It served the Chileans a long time. No fuel was used, and no pollution was produced, nothing but some salt residue. I understand today there's nothing but a few of the splinters of wood and some glass shards because water now has been piped into the area and the still is no longer needed. Nevertheless, more than a century ago, a practical demonstration of solar energy producing fresh water.

I've met one gentleman who actually saw the structure in Slide #6. It was built two miles from where we're sitting right now. The year was 1903 and this was a solar-powered irrigation pump. It's designer/builder claimed $4\frac{1}{2}$ horsepower. I think that might have been optimistic, but it did produce enough power to pump water and 80 acres was irrigated a day. A 35-foot diameter cone with a simple clock-work and weight mechanism, it was pointed at the sun in the morning and then it tracked the sun all day long and pumped water. Many stories are told of its demise. John Yellott has done some research into it and it's his feeling that a hail storm wiped it out. Either this one was rebuilt later on in Willcox, Arizona, or another one was built. That was demolished by a dust devil or windstorm, and another solar age faded from Arizona 70 years ago.

Frank Schuman was a brilliant Pennsylvania engineer. Slide #7 is 1913 in Cairo, Egypt. Far from a tiny $4\frac{1}{2}$ -horsepower engine, this was 60 horsepower and operated at that output pumping irrigation water. Schuman's timing was not good--World War I broke out and this detracted from the interest in solar engines. I understand too that the Egyptian fellahs didn't think much of an engine pumping the water they had been

accustomed to doing by hand--or by foot, rather. There was a lot of political flack and this great solar project too bit the dust out there in the Egyptian desert. I'm sure you're aware that there are several really strong efforts in this direction to provide our southwest farmers with some sizeable solar-powered irrigation pumps.

Slide #8 is 1955, and this is when I really got started seriously thinking about solar. This was the demonstration that took place at the First World Symposium on Solar Energy. Scientists from, as I remember, 35 countries visited Phoenix and brought their equipment which is what you see in the picture. Many of us thought this exhibition was going to trigger a true age of solar energy. But, again, it was a bit premature and within 5 years most people had been disillusioned and solar energy had fallen by the wayside again. It was a noble effort, however, and the beginning of what is now the International Solar Energy Society with a membership of several thousands in 70 countries. We have a chapter here in Arizona, the Arizona Solar Energy Association. I'll say more about that later on.

Slide #9 is the sundial in Carefree. It's still the largest sundial in this country, although not the largest in the world by a long shot. This was built about the time of that hoped-for solar revolution in 1955. Originally, the black area on the top of the sundial was a solar collector and provided hot water for the building in the background. I understand they plan to reinstate that solar heater. The price of fuel has gone up so much in the interim that it would now be profitable to do that again. Perhaps some time in the future we can go out and see the sundial in service again, not only telling the time accurately but providing hot water as well.

Slide #10 was the 1957 solar home on Shea Boulevard in Scottsdale. Winner of a design competition by architects all around the world, this residence was funded by the Association for Applied Solar Energy (which has now become the International Society). You can see the solar collectors in the foreground. They track the sun, and they were also concentrators. Now, there is really no need for concentrators just to heat a house. Movement also made for leaky joints at each end of the collector and this was a problem.

Interestingly, the Goettl air-conditioning firm did the work on this back there in 1957 and Bill Goettl got interested in solar and at that time built himself a solar water heater for his cabin up in the mountains. I talked to him not long ago and he had gone up to check that heater out. It was a copper heater; it had then been up there 20 years and it was still in perfect condition. Now you may have noticed from the papers that the Goettl firm is seriously into solar energy now. They're working on a house in Sun City and also making available solar equipment for heating water and space heating.

Another part of what we thought was a new solar wave, or generation or revolution, was Vanguard, our first satellite, launched in 1957.

Slide #11. Most of us have forgotten or maybe we didn't ever know that it carried some solar cells, which Bell scientists had invented just a few years before. These solar cells functioned well for the entire 7-year life of Vanguard. The whole satellite weighed about 7 pounds, and you can imagine that the small solar cells weighed but little. Someone figured the weight of storage batteries to have operated the radio in Vanguard for 7 years and it came to 300 pounds, which is some indication of the benefits of solar cells.

Another thing took place at about that time; a little fallout from the space effort. Slide #12 was the world's first solar-powered car. This was developed by International Rectifier Corporation, whose president, Charles Escoffery, is in the car. It's an old Baker 1912 electric, and what they did was set the car out in the sun with its 4 x 8 solar panel which is quite visible on the roof. These cells most likely were rejects from the space effort, by the way. They would leave it out for 8 to 10 hours and charge the storage batteries and they could then drive the car around for about 30 minutes. It wasn't too practical a car but at least it was actually operating on solar energy and purportedly getting a ticket from the mounted policeman! It made a good story but they didn't sell any solar cars. Today there are two or three solar cars functioning. The price is still very high and they're not going to displace gasoline for a long time.

We're in another solar age, and I'm hoping this one is going to stick. Artist Bob McCall has done Slide #13, the cover of the August, 1975 Arizona Highways. This is his Solar City, obviously in Arizona. I think his timetable is about the year 1990-2000. Whether it's going to come on that fast remains to be seen but at least this typifies the new solar age that we hope will center in Arizona.

Let's look at the flexibility of solar energy. Slide #14 shows the so-called survival still. It's an earth-water still, apparently invented by the Japanese in World War II. Some of the volcanic islands in the Pacific had no water supply of their own other than what was in the soil and the clever Japanese figured a way to get that out. I'm sure many of you, or at least students in your classes, have made such stills. When I read about it in the journal, Solar Energy, which the International

Solar Energy Society publishes, I couldn't believe it. So I made one and took it out in the backyard to see if it worked. Lo and behold, it did!

Almost immediately, water was drawn up from the ground and condensed on the glass of the still. I took the still out to the desert, set it up, and again it worked, almost immediately. These stills produce about a quart of water a day for a square meter of area, which is about the size of this one. It was actually developed by scientists at the USDA Water Conservation Lab here in Tempe. They did it not knowing of the previous Japanese work, though they duplicated the principles exactly.

The sun shines through the plastic and heats up the hole that you have dug in the desert and this pulls water up from the moist soil. It's really a lot moister than you believe. In fact, they've left one of these in the same site at the Water Conservation Lab and have produced about a quart a day for 30 days on the same site. I've heard of one life being saved by a gadget like this. An Air Force in the near east, I don't know which one it was, made these things part of the survival gear. One pilot crash landed in the desert and stayed alive until he was rescued by producing a quart of drinkable water a day from just this piece of plastic.

The conventional solar still is a little different operation. You start with some water, you don't pull it up out of the ground, but the principle is largely the same. You heat it and vaporize the water. Fresh water condenses on the inside and runs down into a trap and is recovered. A great deal of work has been done on solar stills. Slide #15 is the Puerto Penasco still, in the process of being converted to a hydroponic greenhouse. Those bubble structures are not part of the

solar still. The ones used for the still were flat collectors which laid right on the seashore. They're starting to grow crops under the plastic shown here.

Slide #16 is an artist's concept of the University of Arizona's Environmental Research Laboratory at Tucson which some of you may have visited. They have really spread the word around the world on what can be done with this kind of farming. Slide #17 shows growing shrimp under plastic. Somebody told me they are going to do this with rabbits. Now, rabbits do pretty well even without plastic. I don't know what kind of production they'll get with rabbits under plastic, but that is in the offing.

Slide #18 is McCall's concept of a solar power farm of the future. To service these things, artist McCall invented this ERDA dirigible that goes around repairing the solar collectors or adding to them. So Carl Hodges borrowed the idea and flew the dirigible halfway around the world. Slide #19 is the little sheikdom of Abu Dhabi.

Hodges and others down at the UofA built several of these plastic farm installations in the Tucson area, in Yuma, and in Mexico. Time magazine picked up the story and did a nice feature on it and, of course, Time goes around the world. About a week after the Time article came out, the UofA received a letter from the Sheik of Abu Dhabi, whom up to this point no one in Arizona had ever heard of or knew existed, and he wanted to know what it would cost for one of these installations. The University thought this was idle curiosity, but they came up with a figure. By return mail, here came a certified check for exactly the amount specified! So Carl Hodges and some technicians went over and built this installation, which Carl has the McCall balloon looking down at.

Our Arab friends are very smart. They produce food like that in Slide #20 from those installations. You can do a lot of other things besides grow food with solar energy and the Arabs are getting keenly interested in this. If they realize the importance of it and know that every barrel they don't have to burn in their home country they can ship over to us at \$11 to \$15 a barrel, we over here certainly had better start getting smart about solar energy too.

More on the flexibility of solar energy. The sun, of course, grows all our food and sun drying has been used for centuries, for thousands of years, I'm sure. Here's a little more sophisticated use of the sun to cook food. Slide #21 shows our daughter in the backyard cooking hamburgers with an "Umbroiler." Now, maybe some of you old timers remember that George Löf back 20 years ago invented this thing and put it together and attempted to market it. Unfortunately, he was a little ahead of his time and I'm sure he lost his shirt on this particular device. We bought one and we've had it now for about 20 years and it still works. There are a couple of tears in it but it still does the job. It will cook 2 hamburgers that size in about 20 minutes. You don't have to buy any charcoal in the first place, you don't have to wait for it to burn down, there's no fire hazard, no smoke, no problem of any kind that I know of except high winds and cloudy weather. People say this is an impractical idea because if it rains you're out of business. Well, you're not. You simply turn the Umbroiler upside down and you have a very serviceable umbrella, which is how it started life anyway.

In Slide #22, the young men have cooked some chicken in their solar oven. Really, a solar oven is more practical than the solar reflector cooker. The wind isn't quite as much of a problem and you don't have

to keep pointing the oven at the sun quite as often as you do with the concentrating cooker. Solar ovens can attain temperatures of 375° to 400°. A well insulated one will do that on a clear summer day here in Arizona. They do a good job of cooking.

Slide #23 is the old Shackleford house; it's a museum now. What we're looking at is a solar water heater on part of the roof. That heater has been there for many decades and it still functions. Solar water-heating technology is very low technology. This has been done for at least 50 years and probably longer. Senator Fannin tells of the solar heater on his folks' home when he was a boy. When I was a kid in San Diego years ago, a house that we rented at one point had a solar water heater. The only trouble we had was the time steam came out of the pipes instead of just hot water. The people who make solar heaters today have done a better job and they do produce lots of hot water. The "thermosyphon" principle is a very simple one: put the tank higher than the collector, and you don't even need a pump. The heater automatically circulates and gets hotter and hotter until it reaches an equilibrium point.

Slide #24 is the well-known Mironit solar collector produced in Israel. They've marketed tens of thousands of these and they're available here in Arizona, marketed under the name of Sunsource. This particular one is using the thermosyphon principle and some people find it rather unsightly. There are better ways of doing it. Slide #25 is a little cleaner design in Australia. They simply install the tank horizontally. It's still above the collector and it will thermosyphon. In the United States, most people simply use a small pump to circulate the water.

Slide #26 was my first attempt at a solar pool heater. It's the structure back of my gas lamp, which is off since I think it's not right to burn natural gas for outdoor lamps. I also can't afford to burn gas in my swimming pool heater anymore; it would cost me about \$150 a month in the winter time. The solar pool heater I have now is much larger and raises the temperature about 10° or 12° over normal temperature, extending the season by a good bit. And again, the technology is very low. Solar pool heaters are commercially available as I'm sure you know. You can build one yourself for a good bit less money.

Slide #27 is a commercial installation in Mesa done by a local solar pool heater dealer. Slide #28 is a more elaborate one, a different kind but still a solar pool heater. At the moment, they're functioning as ramadas. Slide #29 is the down position. That's translucent plastic and the heat goes through it and warms the pool. It's the same principle as laying a sheet of plastic right on top of the water. This is fairly expensive, however, and not all of us can afford this. I would like to stress the fact that if you are interested in pool heating, the trick isn't putting heat into the pool. Any solar water heater will do that. The trick is keeping it in. A sizeable pool can lose up to 400,000 BTUs in a single day. This is something like trying to heat your house with the roof removed. So you don't just put the water in; you have to figure a way to keep it in there and this is an attempt to do that.

Slide #30 is the "pool blanket" you may have heard about. The swimmers are unrolling it to cover the pool, or maybe they're rolling it up so they can swim. This is the biggest drawback...it's a certain

amount of work and most people don't want to take the time. So those that are wealthy enough to pump hundreds of thousands of BTUs in through a gas heater and just live with the cost. Lots of us can't do that.

Let's talk now about heating houses which is more important to most of us. Slide #31 is Harry Thomason's original trickling water house built about 20 years ago. It's pretty homely but Thomason proved a point with it. The house is still functioning. That's the solar collector we're looking at; a very simple operation...a pump pumps the water to the top and the water trickles down black aluminum siding. Glass covers it to keep the heat inside, and Thomason has added a reflector which you can see on the ground there to bounce more light onto the collector. The first year this solar roof operated it provided about 95% of the necessary heat. This is Washington, D.C., which is a very tough place to heat. I think they spent about \$4 for oil that year and it has run at about that level ever since. So, figure 20 years at that level and the only problem is the appearance of the house. It's not the most attractive house in the world.

Thomason has gone on and made more attractive ones. Slide #32 is one of the more recent ones. John Yellott visited one recently that was built after this one and says it's more attractive and actually more effective. So Thomason has done some good things in solar heating. Again, recall that his first one had been running for 18 years.

Slide #33 is one of the first solar-heated buildings. It is in Albuquerque, built by Bridgers & Paxton who continue to be leaders in solar engineering. This was about 1956, as I recall, so it has a 20 year track record too. The only mistake they made was in using aluminu

to contain the water. Within six months the water was leaking in a number of places so they had to replace aluminum with copper tubing.

Reynolds Metals claims to have solved the corrosion problem and has a collector which Senator Fannin inspected a couple of weeks ago. They swear there is no more problem with corrosion and I hope this is true because Reynolds is offering the collector for about \$5 a square foot in quantity, which is the best price I've ever heard of.

Slide #34 is a rather strange looking solar house, called Solar One. There have been a number of Solar One's. We have one in Tucson and there's one in Florida. But this is Delaware's Solar One, designed by Karl Boer and Maria Talkas, both solar scientists of long standing. The house was built with some help from Delmarva Power Corporation, a tri-state utility back there. It's unique in that not only does it have heat collectors on the roof but also some cadmium sulfide solar cells which produce electricity. If they can ever get the cost of the solar cells down to a reasonable price, they will replace all the heat collectors with solar cells which will then function as both heat collectors and electricity producers.

They've actually worked out the technical details for running surplus electricity backwards through the meter, thus reducing the homeowner's utility bill! This sounds like a fantastic dream but a number of people, including some utilities, are trying to work out the economic and technical details of such a system. In other words, when your solar house is producing more electricity than it needs you pump it back into the utility grid. There are many problems that have to be worked out but maybe someday we will see some such clever arrangement.

Colorado has done more than any other state that I know of in the field of solar heating. Slide #35 shows a solar house that cools too. They don't really have that big a cooling problem up there but this is a solar heating and refrigeration system at Colorado State University. It's one of three architectural designs but each with a different solar system and Dr. George Löff is largely responsible for this. Colorado State University is a hotbed of solar research. That's the solar collector on the front portion of the roof. That entire half of the roof is black painted metal covered with glass. The absorption refrigeration system doesn't work as efficiently as it should and I'm sure they were using a good bit of backup electric power for refrigeration. The heating part is no problem at all.

Slide #36 is Arizona's claim to the most elegant solar house in the world, and truly it is. This is the Copper Development Association's model solar house, about 10 miles north of Tucson. This house has been functioning now for a couple of years. It's solar heated and refrigerated, using the absorption refrigeration system. That's the solar roof we're looking at. This south half of the roof is all Revere copper collector with square tubes filled with circulating water which is stored in a 3000 gallon underground tank to heat the house in winter.

This house has a little extra feature too...that panel at this end is a solar cell panel that runs a 12-volt TV set, some portable radios, some spotlights, and a security system. Enough to demonstrate that electricity is being produced. When the price of solar cells comes down, we can shingle our roofs and Arizona Public Service will have to get into the business of producing solar cells. But that is not going to happen for a long, long time, if ever.

There is a pool in the background. It has its own pool heater and in the summertime, the pool heater is run in reverse and the water is pumped from the pool through the absorber and radiates its heat to the night sky and cools the pool. So it's not only a pool heater but a pool cooler as well. I understand the price is somewhere in the range of \$250,000 to \$300,000, not because of the solar equipment but because it's a beautiful showplace for the copper and other metal industries.

Slide #37 is Dr. George Löf. He's lectured here at ASU a number of times. A noted world authority on solar energy, the designer/manufacturer of the reflector cooker I showed you earlier, and also designer/builder of this house which has been operating about the same length of time as the Thomason house in Washington. This one is in Denver. It's a different kind of collector, as the flat roof indicates. It's an air system, with heat stored in a rock bin rather than a tank of water. It doesn't produce as much of the necessary heat as the Thomason water house; it does about 40% of the necessary heat. Löf tells us that there have been very few problems with it. He hasn't broken a single pane of glass on that collector on the roof in 18 years.

Slide #38 is the home of Steve Baer, a leading exponent of low-cost do-it-yourself solar technology. Those are 55-gallon barrels we're looking at and there are doors that come up and close at night or at times of cloudy weather. The sun shines on the barrels, heats the water in them and thus heats the house through the night. Slide #39 is of the inside of Baer's house.

Solar homes can certainly be different. They don't all have to look alike. To prove that, one solar design firm thinks that you need

hotter water than the flat-plate collector can provide so they have dreamed up the concentrating roof shown in Slide #40. Water or air or whatever you're trying to heat is in that smaller strip at the top and that curved roof focuses all the rays onto the smaller area and generates very high temperatures. So far it's just an idea; they haven't actually built one. I'd be a little concerned what might happen in high wind.

There have been a number of schools built using solar energy. Slide #41 shows one of them; I believe this is in Virginia. Those panels in back look broken but I think it's just a different kind of glass. They did build one solar school in Boston, Massachusetts, in a pretty tough neighborhood and instead of glass they used Lexan plastic for that very reason. The rocks just bounce off the plastic.

Slide #42 is a school in a suburb of Minneapolis. I want you to notice where these schools are, all in the east where it is very cold. Slide #43 is Timonium, Maryland. This was the first one, I believe. This one has since been retrofitted to solar refrigeration too. They recently added a 150 ton absorption refrigeration chiller. Slide #44 is the Charles Townes school in Atlanta. We do have some solar schools coming up in Arizona. We'll get back to that. But the point is that these solar-heated schools started back in the east. If they can do it up in Minnesota, you know we can do it far easier down here.

Let's talk about solar energy in Arizona. Slide #45 is the first solar-heated condominium we've been able to find in the state, and I'm not just joking. One of our speakers the other day made reference to cave dwelling, how our forebears used what they had available. Our Indians were a good example. This cliff faces south and in winter

their apartments were nicely warmed and stayed warm through the night and maybe even through a day or two of bad weather. In the summer, of course, the overhanging cliff shades the structure and keeps it fairly cool.

In an era of cheap energy, we've forgotten these very basic design techniques. Incidentally, these were known to the Greek writer Xenophon who wrote around 400 B.C. exactly how you should design a house for shading from the sun or exposure to the sun as needed. Now our architects are starting to relearn. People on campus here, Jeff Cook, John Yellott, and others are leading us back in the proper direction.

Speaking of John Yellott, Slide #46 is the pilot model of Harold Hay's "Skytherm" house. This was built at Yellott's Sunnyslope solar lab way back in the 1960's, as I remember. The roof of this house is covered with about 6 inches of water, covered here by the insulating panels. This was summertime when they don't want to heat the water. In the summertime, you cover the water so the sun won't heat it. At night you uncover it and then, particularly with a clear night sky, the water radiates its heat away and cools down. I'm told it can actually cool 25° lower than the ambient air temperature. Thus, the next day you have a reservoir of cool water to keep the house cool. In wintertime, the cycle is obviously reversed. Uncover the water during the daytime and let the sun heat it; cover the water at night to hold the heat inside.

Slide #47 is the first actual Skytherm house. I wish it were in Arizona but it's not. It's in Atascadero, California. Their temperature extremes range from about 25° to 100°F, which is a good bit. The house has operated now for more than 2 years and I understand no supplementary energy has been used for heating or cooling. It doesn't look

much like a solar house. You have to look inside to see what we're talking about. Slide #48 shows the solar ceiling up there. Just above that corrugated metal is 7 inches of water in a clear plastic bag and the water is either warm or cool, depending on what you need. The occupants rated it superior to conventional heating and cooling. Some critics have claimed that you have air stagnation because it's radiant heat. I consider it a very elegant system nevertheless, and predict a brilliant future for it. A modification of this is to be built right here on the ASU campus starting quite soon.

Slide #49 is Prescott's first solar house. I think this winter will be its third winter, as I recall. It's unusual because it wasn't designed at all for a solar house. It was nearly finished and the people decided they wanted a solar home. The architect said, "Well, I don't know if it will work and I've never done a solar house, but I'll get some people from ASU who know about this." They did and there it is, and it's doing about 70% of the necessary heating. In the summer-time, they can also draw on the rock bin, which is their heat storage, for cool air. They run the fan at night and cool the rocks down and then during the hot summer day they can draw on the cool rocks to cool the house.

Slide #50 is Lowell Observatory on Anderson Mesa near Flagstaff. That's a solar collector in the foreground and it will keep the astronomers from freezing on those cold winter nights, or at least there are hopes that it will.

Slide #51 is Arizona's Solar One home, the Consolar house in Tucson. The solar collectors are barely visible so they don't detract at all.

Slide #52 is Flagstaff's first solar house, designed by Herb Wade who is one of our attendees this morning. That's the solar collector we're looking at. It's an air system. The heat is stored in the rocks and Herb said if they needed any cooling in the summer they could use it that way but they seldom need any cooling in Flagstaff. A very successful house.

Slide #53 is the BIRP building, the Beverage Industry's Recycling Plant in Tucson, with a small solar collector on the side. This is an air system too.

Slide #54 is a unique solar house; not quite finished but it will mount Thomason collectors when it is finished. It's in Cornville and is pretty hard to find. Solar houses don't all have to look alike!

Slide #55 is another unique Arizona solar installation. This is Andy's Solar Car Wash in Mesa. Slide #56 shows the roof with the concentrating collector. This doesn't even have a backup heating system. Solar works fine for a car wash because on a cloudy day you're probably not going to get your car washed anyhow.

Arizona is finally getting some solar schools. There is a school in Tucson about to come on-line. I understand that Peoria High is now heating its water with solar collectors. Slide #57 is a model of Tempe's Corona del Sol High School, which ground is being broken for right now. This will be solar heated and have solar hot water. I'm hoping they'll refrigerate it before the project is finished. This did win a sizeable Energy Research & Development (ERDA) grant, something like \$750,000 for the solar part of the school.

Slide #58 is a model of Paolo Soleri's Arcosanti, which will include some solar collectors.

Slide #59 is the solar van that Honeywell runs around the country. It's heated and cooled by the large solar panel which folds up when they're on the road. I think you can see it clearly enough there. They have two solar cooling systems: one absorption refrigeration system and a turbine that runs a conventional compressor. When Honeywell was in Phoenix they were delighted with the sunshine they got the first week. The second week it rained the entire time.

Slide #60 shows Senator Fannin and John Yellott inspecting a Northrup concentrating collector which is one of the few that provides hot enough water for solar refrigeration.

Slide #61 suggests that when we get the cost of solar cells down we'll shingle the entire roof. This was a dream back in that earlier solar age, in the 1950's.

Slides #62 and #63 remind us that wind power is sun power too; Greek windmills, and an old time windmill in our west.

Slide #64 shows one of the newer types, the Darrieus vertical-axis machine. People dream of a little windmill like that in Slide #65 powering an all-electric home. For the 5 kilowatts the average home requires, you would need a 25-foot diameter fan up there, and not many of us can mount something like that on our roof. Slide #66 is one of the BRDA experiments and it's something bigger than you would need for your all-electric home.

Slide #67 shows where the winds are; and Arizona, unfortunately, is not particularly blessed. You can see it's in a low wind area. So I wouldn't advise spending too much money on a windmill.

Certainly we have all kinds of solar energy, as Slide #68 suggests. The Yuma area gets about 100% of possible sunshine, and the rest of

Arizona is not too bad either. The rest of the country doesn't fare nearly as well and yet they do all kinds of good solar things in Minnesota, Washington, and New England.

Slide #69 is from my good friend, Merwin Brown, who tells me this represents approximately one BTU. A good solar collector roof produces hundreds of thousands of BTU's a day.

Slide #70 shows the way we use our energy in this country. You notice space heating alone accounts for 18%. Water heating and refrigeration add another sizeable amount. Then if we add industrial process heat, we have about 45% of our total energy consumption. This is low-technology solar energy; we don't need solar electric power plants to start doing something today.

Slide #71 is artist McCall's concept of the Solar Energy Research Institute. It probably won't look just like that to start with. Maybe someday it could. That's the end of the slides and unless you want to see them over again, we can turn the lights on.

A while back I worked up a timetable for solar energy; some applications are here now and have been here for a long, long time. Of course, domestic water heating is the simplest. It's been around a long time. We can solar heat water right now. But most of us can't see the difference in price; we can't see putting out \$1,000 or \$1,500 for a solar water heater unless we remember that we may be spending far more money on conventional water heating. Recently, a builder said nobody wants to spend \$1,500 for a solar water heater, yet he admitted many might be spending \$25 a month. Well, \$25 a month is \$300 a year and 5 years is \$1,500. I was pleased to notice that Cavalier homes is now making solar water heaters available in their new homes, and a number

of other builders are doing this too. According to the best statistics I can come by, 4% of the energy used in this country goes for heating water. So it's not a small item; it's sizeable.

Heating homes, of course, takes far more energy, and I think this is where solar energy can make an even greater contribution. We don't have to wait for sophisticated solar power plants. Those are probably going to come but we can't expect solar electricity in the next several years. We can expect to heat our houses with solar energy, though. It's already being done in many homes.

Dr. William Shurcliff's book lists the solar homes in the country. Its last edition listed something over 200. But this can't be accurate because he listed only 8 homes for the state of Arizona, and I know that we have between 40 and 50. I think that is probably a conservative estimate because every week I learn of some that I haven't heard of before. So, if we have 50 in Arizona and got credit for 8, there must be 1200 or more in the country and they're going to increase very rapidly for a number of reasons.

ERDA has some solar programs which I'm sure you are aware of. The Solar Heating and Cooling Demonstration Act funded our Tempe School. There is a gentleman in Mesa named Daniel Brock who recently was awarded a grant for the solar-heating portion of a residence. That was, again, a part of the Solar Heating and Cooling Demonstration Act. Sixty million dollars was set aside for that purpose. These demonstrations are funded at about 6-month intervals. So if you're planning a solar home, be in touch with the Arizona Solar Energy Research Commission and make an application for such a grant.

Yesterday, Dr. Brent Brown read us some quotes from predictive studies done in the past, none of which seemed to mention the energy problem. He wasn't reading the right reports because in 1952, the Paley Commission reported to President Truman that by 1975 (if we got going in '52) there could be 13 million solar-heated homes in this country! Now certainly there aren't 13 million today and that's too bad, but there are a lot more than there were 5 years ago. More recently, General Electric and others did studies of what can be done with solar energy. The GE portion suggested that by the year 2000 the potential market is something like 40 million structures which could be solar heated and/or cooled. So the potential is tremendous. At the National Building Show in Chicago late last year, one speaker predicted that by 1980 there would be 500,000 solar buildings. That may be optimistic, but maybe not.

A recent study by Stanford Research Institute was commissioned by the Sheet Metal Workers International Union. This study projected a \$4-billion-a-year solar industry by 1990 and I would consider that fairly conservative. A similar study by the Mitre Corporation for the sheet metal workers projected 2.4 million single-family residences, 80,000 retail stores, 67,000 office buildings, and 22,000 multi-family residential units by the year 1990, solar heated and/or cooled. To get back to that GE prediction of 39 to 40 million possible market by the year 2000, obviously they're not all going to be solar. But even a tenth would be a tremendous application.

Now I want to move on and talk about solar energy and the educator. Again, it's great to be talking to you who are, or can be, missionaries for solar energy. I think the solar-heated school itself (we do have

three in the state that I mentioned, and I'm sure others will come) can be a great teaching tool for solar energy. In the one slide we saw students looking up at the solar collectors on the Timonium School. Some schools have actually been funded partly as workshop demonstrations of solar energy. You don't just build the solar collectors on the roof, but you arrange to teach the students how it works. You also bring in people from the neighborhood to see how the solar school works. So there is one way the school can do great good things for solar.

I have a list here of solar energy courses available at colleges around the country and practically every state in the country is mentioned. Our own state figures strongly, in that Arizona State University has for years had solar programs. The same holds for the University of Arizona and Northern Arizona University is coming on strong now and has a number of formal solar programs. Our community colleges too are involved. Not too long ago Phoenix College had a two-weekend workshop in which the participants actually built their own 4 x 8 foot solar collectors. Built them and operated them to demonstrate that they were actually heating water. Yavapai Community College in Prescott has an active solar program.

I think we're fairly well covered at community colleges and the universities, but we need more in the high schools. We need more in the grade schools. And here is the beauty of solar energy, because a grade schooler can comprehend what you're talking about. The technology is not that complicated until you get into solar cells and how they operate. Low-technology solar is something that a 6- or 8-year-old can understand. A burning glass anybody can comprehend. We've all used them since we were kids. I was very pleased yesterday to hear Mrs. Warner say that shortly the department will have some kind of book or pamphlet available

for science teachers on solar. Now last year I spent a good bit of time with Mrs. Warner, Fred Sughrue, and Lyman Jackson (who will be speaking to you). Dr. Handy met with them a number of times, too. So it's nice to see these things coming along. This is what we need.

Science fairs for a long time have been great showplaces for solar energy. I thought I kept very good close track of what was going on but I don't always succeed. ERDA puts out a newsletter each week and here in the latest one it says "ERDA energy award winners named at International High School Science Fairs." I wonder if anybody in the room has heard of these ERDA awards for high school science fairs. Anybody? Great secret. Of the ten winners in science, 6 were solar energy. This is positive proof that interest is strong in solar energy. This isn't a very controversial subject; I think everybody is for solar. You'll find the kids are really turned on already and it's not going to take much on our part to foster that interest.

I told you I brought along some material and if you don't have them yet, get them. Arizona Highways, in case you missed that one, the all solar issue last August. ERDA has done a nice little booklet on solar energy, I'm hoping ERDA is going to do far more. I drooled when I saw that book yesterday on fossil and nuclear power plant technology which ERDA funded for the State of Pennsylvania, including a teacher's guide. These are the kinds of things we need in solar energy. Maybe we can get busy and Mrs. Warner's department can apply to ERDA for funding for a similar solar book.

Arizona's Solar Energy Research Commission; I hope that you're all familiar with it. They're in the Executive Tower at the Capitol. They've done this little book, "Putting the Sun to Work in Arizona"; do get a

copy of this. Arizona Public Service very kindly funded it; they published 30,000 copies. I think that as programs in the schools go on it will be possible to print more and make them available to our students.

The Commission also publishes a Solar Energy Directory. Unfortunately, Judi Wright at the Commission was just about out of these. There aren't as many as I'd hoped to bring, but you can get in touch with the Commission and get a copy. This one lists 87 engineers, architects, manufacturers, and distributors of solar equipment in the state of Arizona alone. The Commission has a bibliography, too, books about solar energy. There are a number of these out there and they tell you where to go for books on the subject. There is also a smaller one, Solar Energy Publications by the International Compendium, a listing of solar materials available. And finally, a newsletter from Senator Fannin on solar energy.

I'm going to wrap this up very quickly now. Recently, a young prince from Saudi Arabia, probably looking like the gentleman we saw in the slide, came to our country and brought a check for \$150,000 for the city of Reston, Virginia. This was the down payment on the total gift of \$570,000 so that Reston could solar heat and cool a new school building. All the prince wanted in return was the opportunity to monitor the project with an eye to applications for his own country!

The Shah of Iran is seriously shopping for solar equipment for the remote villages in his country. Abu Dhabi has the highest per capita wealth in the world, and they have a University of Arizona solar greenhouse producing vegetables, as we saw. They are also getting into all kinds of other solar things. Such an interest on the part of the nations

who hold much of the world's oil wealth should be instructive to us because it is immoral, unwise, and terribly expensive to import petroleum and simply set fire to it. The quicker we begin the shift to alternative energy sources the better.

I want to read you two quotations. The first is by Professor Valentin Baum, the Russian pioneer in solar energy. He wrote this for the first World Symposium on Solar Energy--you recall that was back in 1955, right here in Phoenix and Tucson. Here's Dr. Baum's message:

"Just imagine for a moment that mankind had based his power industry on solar radiation, not fuel. And then the proposal to use different kinds of fuel was proposed. Probably there would have been very many objections. One could imagine one of the most important arguments in defense of solar would be formulated as follows: Solar radiation is a noble form of energy and it was under its influence that life originated and continues to develop on Earth. Therefore, its use, no matter on what scale, represents no danger or inconvenience for either the floral or fauna of the world. The use of any other kind of fuel would inevitably be connected with the poisoning of the atmosphere, the water, and the land. Fuel should be used only where there are no other possibilities for obtaining energy and in the sunny regions of the world the energy of the sun should be used."

Here's a thought from Dr. Freeman Dyson of Princeton's Institute for Advanced Studies. He says, "Society has the option of limiting its growth either by conscious decision, by stagnation, or by disinterest. The society in which these internal limits are absent may continue its growth forever."

Our speaker, Mr. Heller, said yesterday that he wasn't pessimistic, he was optimistic. He thought we could continue the energy lifestyle to which we've become accustomed, not being wasteful but by being intelligent and making use of other sources. For many years a growing band of solar proponents have been claiming that the sun could provide a good

portion of our energy needs. Now for a variety of reasons, solar's time seems to have come. Barring a sudden new discovery of new supplies of oil and gas, the collapse of the environmental movement, or the successful operation of a commercial breeder or fusion plant, solar energy is about to be given its chance to shine. By the year 2000, solar energy will have made it or will have flopped. I hope to be on hand to see if I was right or wrong. For today, I'll be satisfied if I've made just a few points about solar energy clear.

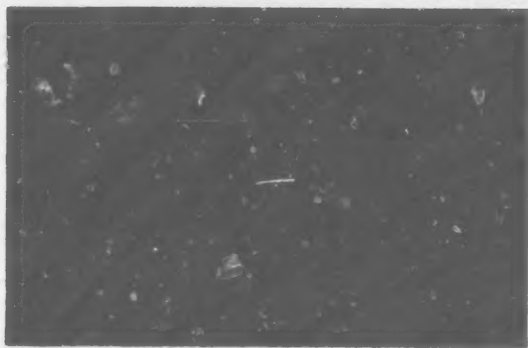
I want to give you my five solar laws in conclusion:

1. There is more than enough solar energy for our needs.
2. Solar energy is a flexible source suitable for rooftop or backyard, as well as large-scale central power plants.
3. Solar energy is about as safe as anything I can think of, unless the central tower of a huge solar power plant falls on you!
4. Solar energy falls, like the rain, on the just and the unjust. And though I hate to mention it too loudly, it is not yet taxed.

Last, and perhaps best...

5. The only way to waste solar energy is not to use it.

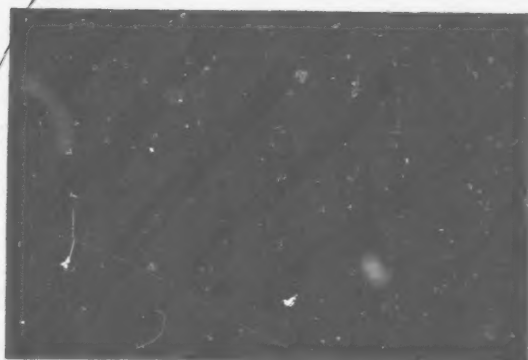
Go now and spread the solar gospel to your classes!



Slide #1



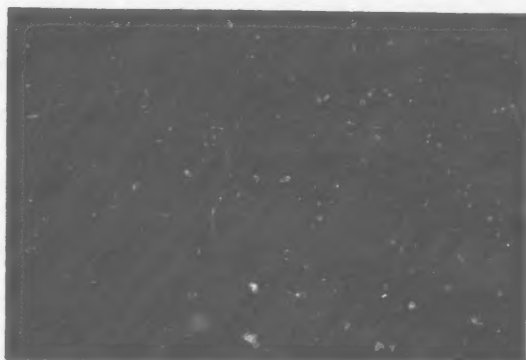
Slide #2



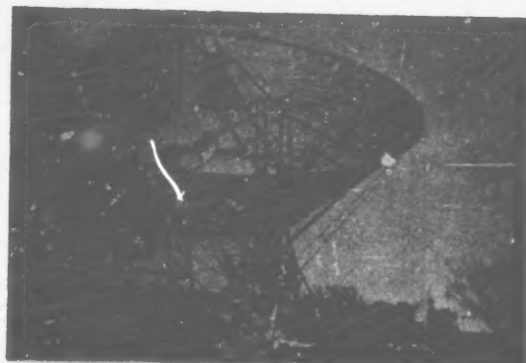
Slide #3



Slide #4



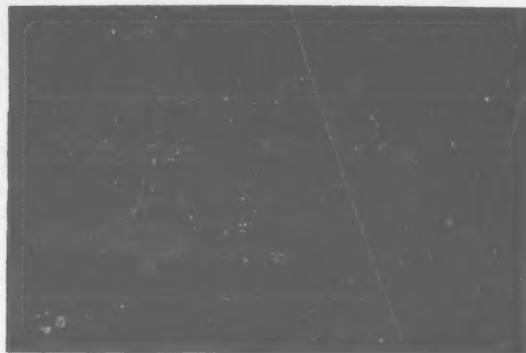
Slide #5



Slide #6



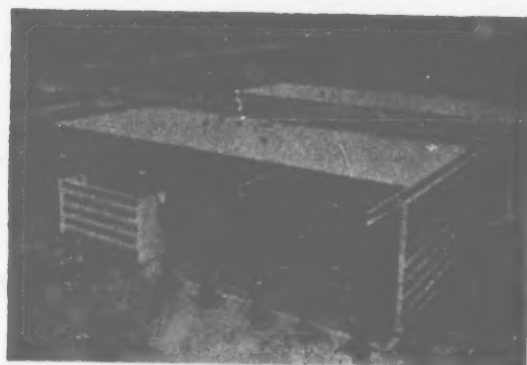
Slide #7



Slide #8



Slide #9



Slide #10



Slide #11



Slide #12



Slide #13



Slide #14



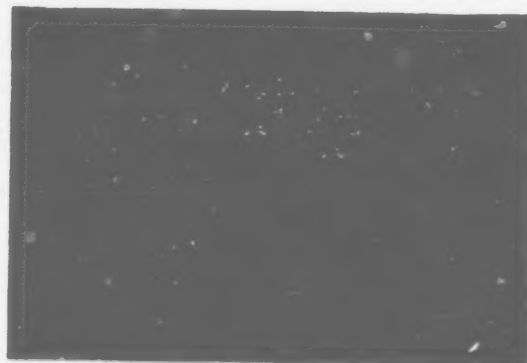
Slide #15



Slide #16



Slide #17



Slide #18



Slide #19



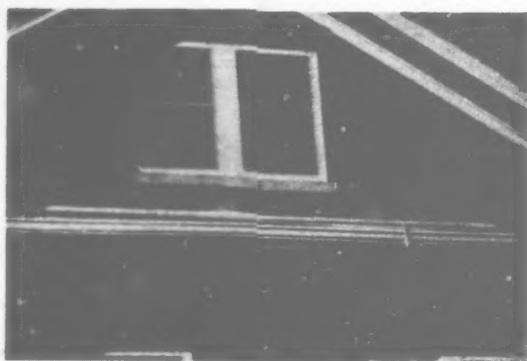
Slide #20



Slide
#21



slide #22



slide #23



Slide
#24



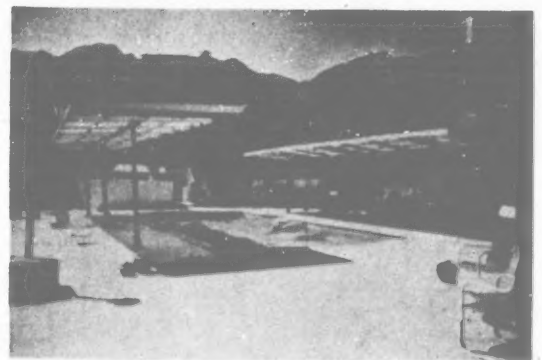
Slide #25



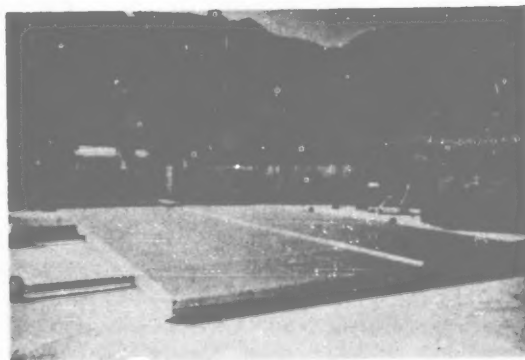
Slide #26



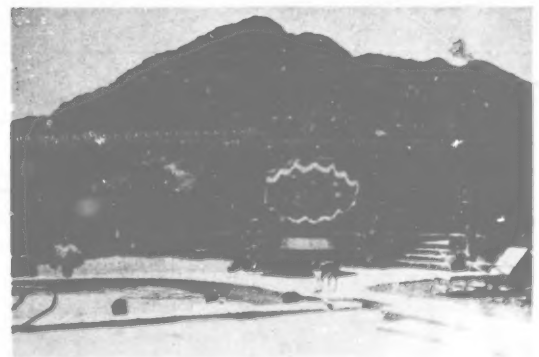
Slide #27



Slide #28



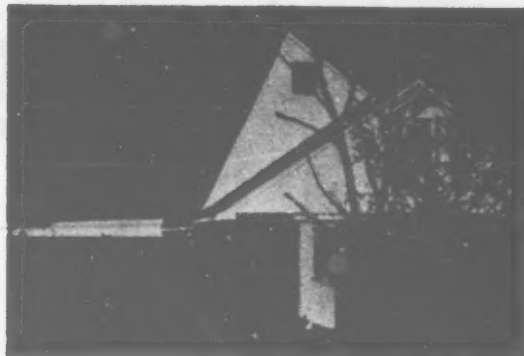
Slide #29



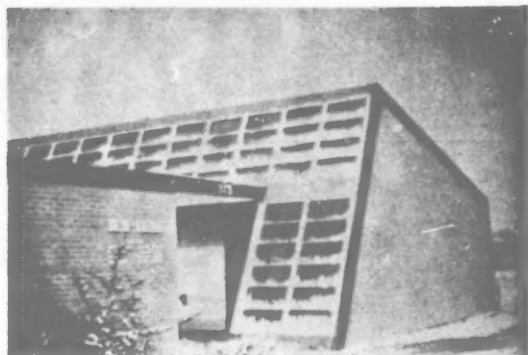
Slide #30



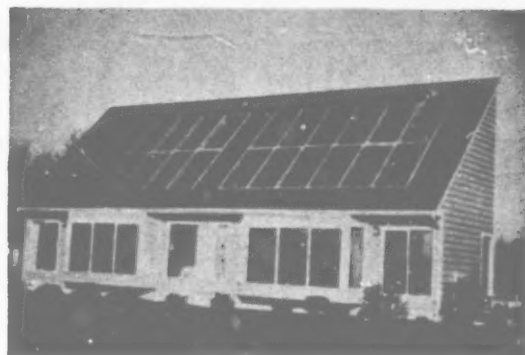
Slide #31



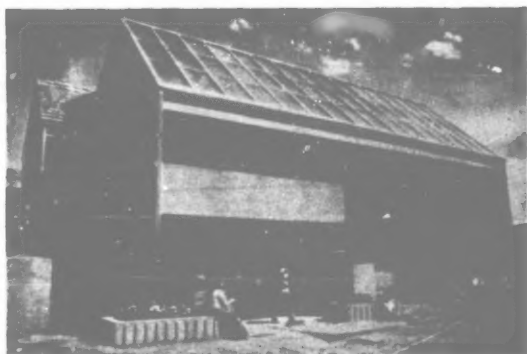
Slide #32



Slide #33



Slide #34



slide #35



Slide #36



Slide #37

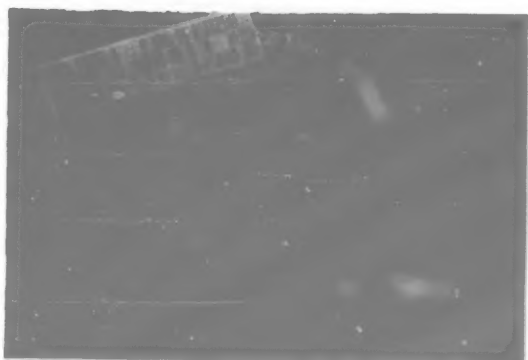
Slide
#38



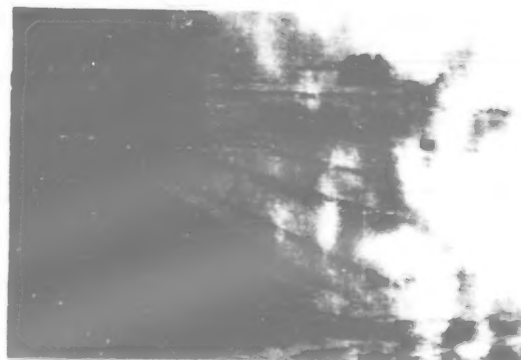
Slide #39



Slide #40



Slide #41



Slide #42



Slide #43



Slide #44



Slide
#45



Slide #46



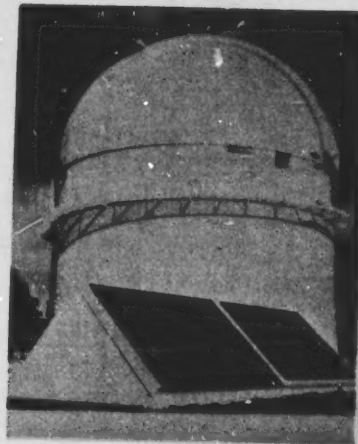
Slide #47



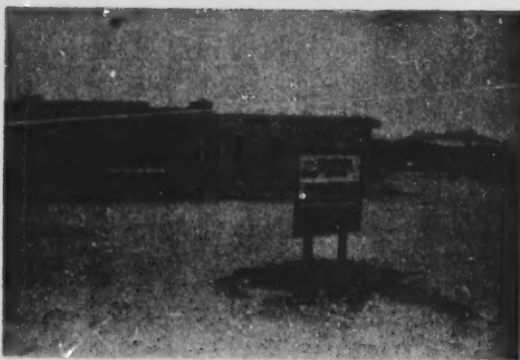
Slide #48



Slide #49



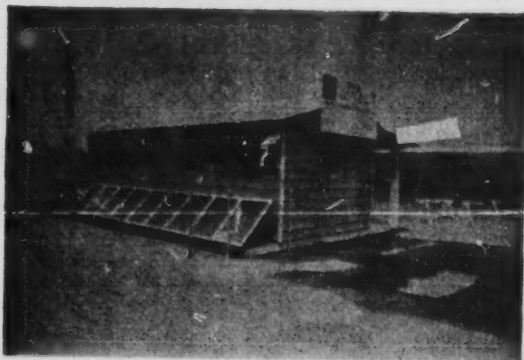
Slide
#50



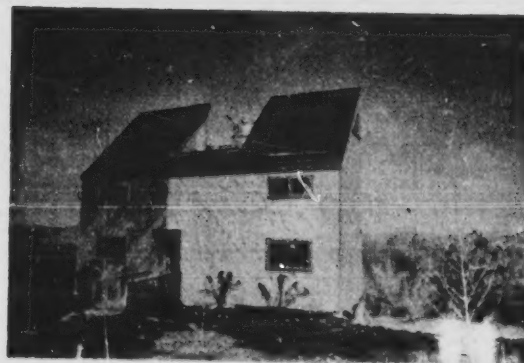
Slide #51



Slide #52



Slide #53



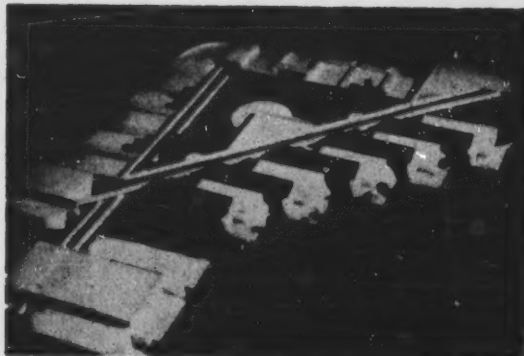
Slide #54



Slide #55



Slide #56



Slide #57



Slide #58



Slide #59

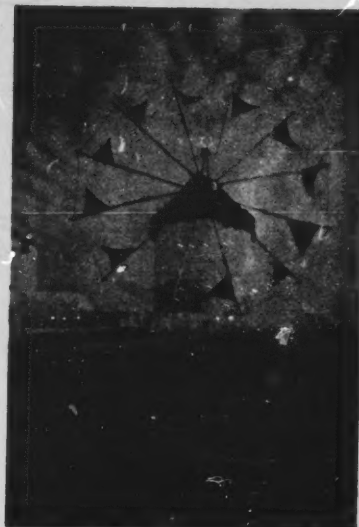


Slide #60



Slide #61

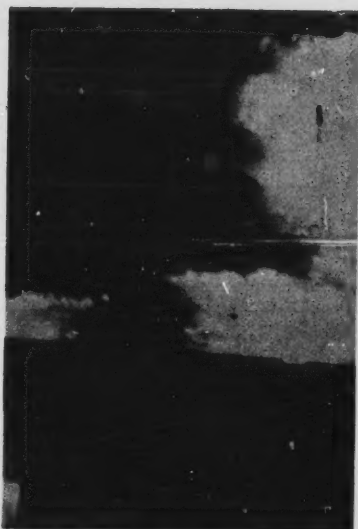
Slide
#62



Slide
#63

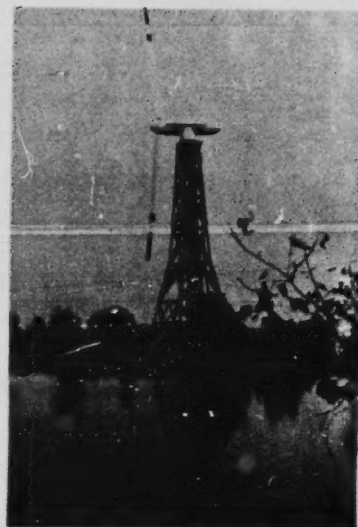


slide #64



Slide
#65

Slide
#66





Slide #67



Slide #68



Slide
#69



Slide #70



Slide #71

UTILIZATION OF SOLAR ENERGY FOR POWER

**By
DR. CHARLES B. BACKUS**

**College of Engineering Sciences (Mechanical)
Arizona State University
Tempe, Arizona 85281**

UTILIZATION OF SOLAR ENERGY FOR POWER

A great deal has appeared in the popular press during the last two years concerning solar energy as an alternative energy source. Solar energy has been promoted by some enthusiastic supporters as a panacea for the U.S. energy problem. The claims are that it is readily available, it is free, and it is non-polluting. Although these statements are basically correct, the engineer must consider more detailed questions, such as are these systems economical compared with other alternatives, and can these systems make a significant impact on the energy usage in the United States. Solar energy utilization does involve more than traditional engineering problem analysis in that it must take into account the social and political consequences of other energy usage alternatives. It appears from most indications, both technical and non-technical, that the time for solar energy utilization is now.

To put solar energy in better perspective, I would like to point out two misconceptions usually associated with solar energy. The first of these is that solar energy is something new. Engineering applications utilizing the sun as a source have been seriously pursued for at least 100 years. Captain John Brickson in the 1960's and 70's built several solar driven steam engines for a variety of applications. In 1902 we had solar driven irrigation pumps in Arizona, and in 1913 a very large solar irrigation system was installed in Egypt by a

Philadelphia firm. It was only the advent of the automobile and inexpensive gasoline and oil which terminated the serious engineering investigation of solar devices. Another peak in solar activity occurred in the mid-1950's when a World Exposition was held in Phoenix, Arizona, for the display of solar devices. An International Solar Energy Society was formed at that time and had its headquarters at Arizona State University. Most of the solar activities at that time were directed towards less developed countries. Solar cookers, solar distillation systems, and low technology solar heating applications were being pursued. These low technology solar devices were never accepted by the developing countries, mostly for sociological reasons. These devices did not fit within their lifestyle. As a result, the International Solar Energy Society decreased in membership until 1970, when the headquarters were moved to Australia. Australia along with Japan and Israel were the countries most active in solar energy research and industry at that time.

A second misconception about solar energy is that it is most prevalent in the southwest United States, and particularly in Arizona. Referring to Figure 1 giving the total amount of solar energy incident per unit area in various parts of the United States, one can see that in general solar energy is available in significant quantities throughout the United States. The energy available in most of the United States is at least 70% as much as that available in Arizona. We tend to correlate solar energy incidence with weather, which is just not correct. Indeed, some of our studies at Arizona State University indicate that solar energy for heating of buildings, for instance, is going to be

much more significant in the northern parts of the U.S. This is because the cost of solar collecting devices is about the same per square foot in Minnesota, say, as it is in Arizona. However, the requirement for heating is so much more in Minnesota that the fuel savings are much greater per square foot per year. Therefore, the impact for solar energy for heating of buildings is going to be very significant in the northern part of the U.S., not in the southern parts which have more solar energy.

In 1971, President Nixon ordered a re-evaluation of our future energy requirements in the U.S. A panel was set up of joint National Science Foundation and NASA personnel to evaluate the potential of solar energy. Up until that time there had never been a solar program in the U.S. The conclusion of this panel was that solar energy could indeed make an impact on energy requirements of the U.S. beyond 1990. In order to make a contribution, however, we needed to establish a solar energy research program to bring a solar industry into being. A solar energy program was established in the National Science Foundation and later transferred to the Energy Research and Development Administration in 1975. This program has grown from a zero annual funding level to over \$100 million for the current year. A review of that program budget (see Table 1 showing the budget history of the program) reveals the growth of that program and also the diversity within the program. The major emphasis in this program is currently on the heating and cooling of buildings because it is felt that is the nearest term technology. However, most of the research monies are going into electrical generating techniques.

For electrical generation one usually uses solar concentrators which can only use part of the sunlight available. Figure 2 shows a different insolation distribution pattern than that shown in Figure 1. This represents the amount of energy that's incident over a year's time in the country that comes directly from the sun. Direct means that it isn't scattered by clouds and other constituents of the atmosphere. This direct part of sunlight has a much more unequal distribution across the U.S. One can see that for thermal power generation, Arizona and southern California are indeed favored locations. In the future, if it's proven feasible and economical, Arizona may be a producer and exporter of electrical power from a solar source. Presently, Arizona imports about 85% of its energy from outside the state borders.

When solar power plants were considered, the first system considered was the parabolic trough concept similar to that used in Egypt in 1913. The parabolic trough focuses the sun on a line down the middle of the parabola and it rocks back and forth to follow the sun. It has the normal disadvantages of solar plus the added disadvantage of using only direct sunlight. An artist's concept of a large power plant using these parabolic troughs is seen in Figure 3.

Most of the solar-thermal effort in the last couple of years within the U.S. has been concentrated on the central receiver or power tower concept, shown in Figure 4. This concept uses flat reflective mirrors that are mounted on the ground and reflect the sunlight back to the top of a tower, which is a boiler. All the steam is generated at one central point as opposed to the other concept where the hot pipes are distributed over the field. There are obviously more thermal

losses in the distributed system. All of the energy transfer in the central receiver concept is by light and the boiler is the only hot surface. The main technical challenge of the concept is to design the boiler so that it doesn't melt under any of the extreme circumstances. The concentration of sunlight at the boiler is about 1000 times the intensity of normal sunlight. One has to make sure that the boiler maintains its mechanical integrity as clouds pass and it suddenly heats up and suddenly cools down. The mirrors are a lot less complicated and cost less per square foot than do the other things but it turns out that the first surface that intersects sunlight dominates as the most costly part of the total system. One can afford to pay quite a bit per unit area for the boiler because it doesn't add percentage-wise very much to the cost of the total plant. However, a slight change in the costs of the mirrors significantly affects the cost of electricity generated.

Figure 5 shows a reference design for a 100 megawatt electric power plant that requires a field that is .7 miles on the side. (That power level is about one tenth the size of the first nuclear plant being built on the west side of Phoenix.) The tower in the middle of the field is almost 1000 feet high. Each of the mirrors are about 20 feet on the side. These are fairly large structures and one has to insure that they don't blow away in the wind and track the sun accurately enough to hit the tower.

Figure 6 shows an artist's concept of what the power tower concept would be in a large power plant size. The U.S. has committed itself to building a 10 megawatt electric power station of this type of design.

That station has been under design for about a year and a half by a number of different companies in the U.S. The site for this pilot plant will be selected in January 1977. The Arizona utility companies, with the leadership of Arizona Public Service, has proposed that this pilot plant be located in Arizona with the utilities contributing about 10 million dollars toward the cost of building the plant.

The basic technology of the power tower concept has been demonstrated in the French solar furnace shown in Figure 7. This furnace has been in operation since before 1970. Each of the flat mirrors are about 20 feet on the side. The mirrors move and reflect the sunlight directly into a nine story building with a parabolic shaped curvature side which is mirrored. The parabolic shaped building does the concentration down to the central tower building seen in front. This is not used for power generation but it is used for as a high temperature furnace. It provides a very clean atmosphere and high temperatures up to about 3500°C , and has been used primarily for high temperature materials research. The U.S. has used this furnace in the past for space related research and presently has an agreement with the French for testing a small solar steam generator.

The experience with this system has shown no major problems with materials, winds or tracking. The amount of energy reaching the one cubic foot focal zone is 60% of the energy incident on the primary mirrors. This indicates high tracking accuracy and reflectivity since the light is reflected twice and focused down to that one cubic foot. The primary mirrors have only been washed twice and the building has never been washed.

Figure 8 shows the result of an Aerospace Corporation study to compare the cost of electricity from a solar power plant with a conventional power plant. The largest part of the cost in a conventional power plant is the fuel cost. In the solar case, there is no cost for the fuel but one has to have a huge capital investment in order to use that so-called free fuel. As a result, the largest part of the cost of the solar plant is just the cost of money and that dominates essentially as much as the fuel cost of the conventional power plant. The total amount of cost per kilowatt-hour is indicated to be about the same, so one is trading a fuel cost for a capital cost. The other main costs in solar are the depreciation and the insurance which are capital related.

An item that most people don't talk about is the water requirement for solar power plants. Solar thermal power plants are just steam generation plants, fossil fuel or nuclear and require cooling water just like any conventional power plant. They may even require more cooling water if their thermal efficiencies are lower than conventional plants. Presently, nuclear power plants require more cooling water per electrical kilowatt than does a fossil fuel plant. That may change in the future, but that's strictly determined by the efficiency of the plant. If a solar power plant is 20% efficient, even if the cost is low, it's going to require a lot more cooling water. One can compare how much cooling water is required for various kinds of solar concentrating systems and it gets down to an efficiency argument that the more efficient the conversion system then the less water is required. Recalling the map of the United States in Figure 2, that shows the concentration of direct sunlight is in the Southwest and that is exactly where the water is not. Southern California and Arizona in

particular are very attractive areas for solar power plants and of course, are very dry as far as water availability for the production of power. The water in the Colorado River is already over allocated and if the water was used for cooling, it would raise the temperature, increase evaporation, and increase the salinity of the remaining water which is already a problem. So there are a lot of issues connected with cooling other than just the purely technical ones.

A non-thermal way of converting sunlight into electricity is with solar cells. The solar cell is a solid state piece of glass-like material that when exposed to sunlight, generates electricity without any moving parts or without any heat generation. These devices have been used to provide essentially all of the power for the space satellites. There have been over 1000 satellites launched that are powered with solar cells. The communication satellites using solar cells make it possible for us to watch the Olympics in our home, live from anywhere in the world. But the requirements are considerably different in outer space. One can afford to spend a lot of money for these kinds of converters if they are extremely reliable and predictable. Satellites with power levels from a few watts to over 20 kilowatts have been used.

The technology of these solar cells that have been so successful in space is being investigated for terrestrial applications. The cost of space cells is very high but in the last two years the cost of terrestrial cells have come down from about \$200 per peak watt to \$15. It is expected that these costs will continue down to about \$0.50 per peak watt by 1985. These cells are presently made from silicon which is the second most common element on earth. These cells convert about

20% of the sunlight into electricity. The U.S. solar program is aimed at bringing the cost of solar cells down and ensuring that they can be encapsulated to withstand the terrestrial weather conditions without deteriorating. Very little experience has been obtained on terrestrial lifetimes for these cells. There is a solar cell array in Chile that was made in France and has been exposed for about 15 years without degradation. It is enclosed under glass, which is a very good encapsulate. There is no inherent mechanism within the solar cell that would wear out in any way, other than letting the water get into it and corroding off the electrical leads. Plastics are being looked at now, of course, but the plastic may deteriorate. With the encouraging development of solar cells and markets within the last couple of years, there have been four or five new companies formed just to make terrestrial solar cells. Some of those are big investors, such as Mobil and Shell, forming new companies just to make terrestrial solar cells.

Present applications are mostly for power at remote locations. It is much cheaper to use solar cells rather than batteries for terrestrial applications in these remote areas. A typical application is shown in Figure 9. This installation is near Atlanta and it just runs a railroad crossing by providing power to ring the bells and flash the lights when a train comes. All the other times it is sitting there charging the battery. It is cheaper to install this system than to run an electrical line a couple of miles. Solar cells are becoming more common and people are considering them as an alternative where two years ago no one even thought of using solar cells. As a result, the price has come down considerably. The production for space cells

has remained the same for ten years--about 50 kilowatts capacity per year. Last year there were four times the number of terrestrial applications compared with space applications. The space market is becoming a very small part of the solar cell market and the cost, as a result, is coming down. There are various ways that one can make projections for lowering the cost of solar cells. One is just in the production rates--cells are extremely labor intensive and are often referred to as jewels. They are not mass produced items. In one of my tours of a solar cell plant, I was told that an individual cell was picked up by 40 different individual persons during the processing steps. The present cost is about \$13 per peak watt and these are encapsulated and everything ready for terrestrial use. The Army is considering some large scale purchases because they have a lot of special applications for remote, portable power sources. That would stimulate a large investment by private industry in capacity and the cost could come down considerably. The U.S. government is spending about \$25 million this year on ways to lower the cost of solar cells for terrestrial use. These studies are involved all the way from the chemical processing of sand all the way up to the final assembly of the arrays.

Mobil Oil has set up a new company called Mobil-Tyco-Mobil and has put up \$30 million for this new company just for the investigation of a particular technique for the production of terrestrial solar cells. Shell Oil is putting \$6 million into a company to build cadmium sulfide cells. This is a different type of cell that does not use the silicon and has several advantages. This cell uses thin-film type technology and can be sprayed on or dipped in various chemical batches that

lends itself to cheap processing. This is just one of the promising areas for extremely cheap electricity from solar cells.

Another way of reducing the cost of solar cells is just concentrating the sunlight on them. If you put ten times the amount of light onto a solar cell you can get ten times the amount of electricity out. As a result, if you can build the concentrator cheaper than you can build the cell, then you can reduce the area the cell required per electrical output and therefore, the cost of electricity. This is one of the areas we are pursuing at ASU. Figure 10 shows one of the silicon cells being used with a fresnel lens. We have concentrated on silicon type cells up to about 80 suns. Other people have developed a particular type of cell (gallium arsenide) that lends itself to concentrations up to 2000 suns. Under that illumination, they had an efficiency of over 19%. Concentration is just another alternative way of getting to lower power costs.

One of the things that a U.S. company should consider in getting into the solar energy business is the potential of the export market. There are several places outside of the U.S. where energy costs are now very high and solar could be very competitive presently. Even within the U.S., several applications of solar will become economically justified in the near future. However, it is very difficult to make a significant impact on the energy patterns of the U.S. If solar devices were economically justified today on new houses, it would take many years before the recycling of new housing construction would reflect an impact of the solar devices.

Undoubtedly, solar energy devices will be the best economical choice for certain applications and areas of the country. Also,

clearly other energy sources will be the most economically attractive alternatives for other applications and locations. There have been several projections of the impact that solar energy would have on meeting the energy requirements of the U.S. For the year 2000, these projections vary from 1% up to a maximum of 30% as the amount of energy that could be supplied from solar sources. In my estimate, a 10-15% contribution to the energy requirements of the U.S. by the year 2000 would be likely and highly desirable.

Solar energy is not a panacea of the energy problem of the U.S. However, none of the other energy alternatives are either. We do not have an energy crisis, but rather a national energy problem which will dominate both foreign and domestic policy for at least the next generation. As best I can judge, we will need all of our energy resources fully developed in order to survive. This includes nuclear, fossil, solar, geothermal, etc. We will have to accept as Americans that energy expenditures will increase both personally and nationally in the future. We cannot afford to curtail any of our energy alternatives for promotion of another. Indeed, we don't have energy "alternatives" --we need them all!

TABLE 1

US NATIONAL SOLAR ENERGY PROGRAM
\$ MILLIONS

	NSF					ERDA	
	FY 71	FY 72	FY 73	FY 74	FY 75	AUTHORI-	OUTLAYS
						ZATION	
						FY 76	
<u>SOLAR ELECTRIC APPLICATIONS</u>							
SOLAR THERMAL	0.06	0.55	1.43	2.2	13.2	19.3	15.6
PHOTOVOLTAIC	--	0.33	0.79	2.4	5.0	22.4	16.4
WIND ENERGY	--	--	0.20	1.0	5.3	15.1	11.1
OCEAN THERMAL	--	0.14	0.23	0.7	1.9	8.1	6.0
	<u>(0.06)</u>	<u>(1.02)</u>	<u>(2.65)</u>	<u>(6.3)</u>	<u>(25.4)</u>	<u>(64.9)</u>	<u>(49.1)</u>
<u>DIRECT SOLAR CONVERSIONS</u>							
HEATING AND COOLING	0.54	0.10	0.40	5.9	12.5	39.9	28.5
BIOCONVERSION	0.60	0.35	0.65	1.0	2.0	4.5	3.8
TECHNICAL SUPPORT	--	0.19	0.25	--	--	5.4	4.6
	<u>(1.14)</u>	<u>(0.64)</u>	<u>(1.31)</u>	<u>(6.9)</u>	<u>(14.5)</u>	<u>(49.8)</u>	<u>(36.9)</u>
TOTALS	<u>1.20</u>	<u>1.66</u>	<u>3.96</u>	<u>13.2</u>	<u>39.9</u>	<u>114.7</u>	<u>86.0</u>

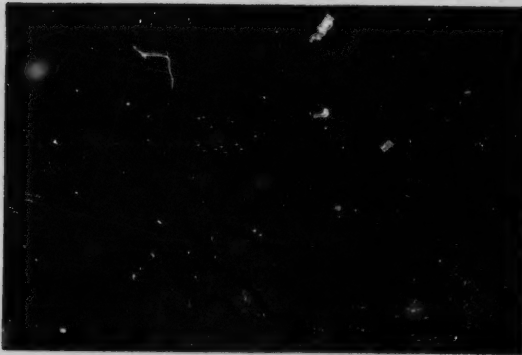


Figure 1 - Mean total isolation isopleths in the U.S.

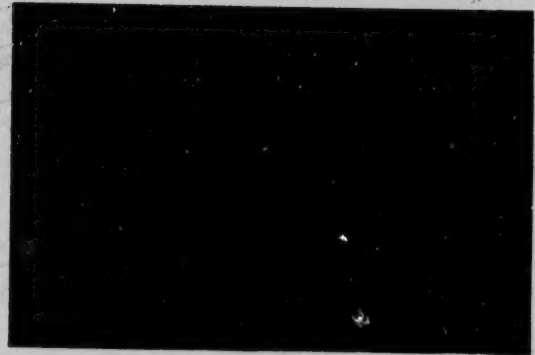


Figure 2 - Distribution of the energy that comes directly from the sun and is available for concentration applications.



Figure 3 - An artist concept of what a large solar-thermal power plant may look like using parabolic troughs as collectors. (Courtesy of Grumman Aerospace Corp.)



Figure 4 - The central receiver concept for a thermal power plant.



Figure 5 - A schematic of a reference design for a 100 MW central receiver power plant.



Figure 6 - An artist concept of a solar thermal power plant. (Courtesy of Honeywell Corp.)



Figure 7 - The French solar furnace that delivers 1 MW of thermal energy to its focal zone.



Figure 8 - A comparison of the cost of electricity from solar and fossil sources. (From The Aerospace Corp.)



Figure 9 - A solar cell array
operating a railroad crossing near
Atlanta. (Courtesy of Solar Power
Corp.)



Figure 10 - A silicon cell being
tested with concentrated sunlight
from a fresnel lens.

NATURAL RADIATION ENVIRONMENT

By
DR. JOHN W. MCKLVBEN

**College of Engineering Sciences (Mechanical)
Arizona State University
Tempe, Arizona 85281**

NATURAL RADIATION ENVIRONMENT

We are about to begin a group of sessions which can become very emotional--the nuclear dialogue. I would like to present my side from a factual, academic posture and refrain from taking sides one way or another. My profession is that of a nuclear-environmental engineer; one who measures low-level radiation and observes radiation effects. I am not an individual who builds nuclear power plants, nor one who has a vested interest in that area, other than that of an educator. I would like to make it absolutely clear that my philosophy is one that---we need all the energy options and new technologies as they become available with due consideration given to safety, environmental and economic impact, and demand. We have to look at the benefits and the risks.

With that introduction, let's take a look at radiation in general, and naturally occurring and man-made radiation in particular. Some of the remarks that I will make are applicable to coal and geothermal as well as atomic power, perhaps even cigarette smoking and eating. To set the stage, let's first ask the question, what is radiation? What are radioactive materials?

There are several nuclides, some light but particularly those having atomic numbers greater than lead which have an unstable nucleus. Its like you living in a house with a wife and a mistress. If they are not the same, there is going to be a bit of dischord, a little bit of agita-

tion, and certainly some tension. This is analogous to a radioactive nuclide which has too many protons or neutrons in its nucleus. After a period of time (some very soon; some after centuries; some after millenia), an event or decay occurs in which some type of radiation is emitted from within the nucleus. The result is an increase in stability ---the unwanted excitation or tension has been removed.

Radioactive decay can be manifested in different forms of radiation. It can be an emission of an alpha particle, a beta particle, a neutron, gamma radiation, or various combinations of these. For today's discussion, let's recognize the fact that different materials emit different forms or combinations of radiation, but for our work, we are only concerned with the end result; the physical and the biological effect of these radiations on living species. That is to say, the end result of radiation striking living organisms. Let's lump the radiation sources together into one entity and create a representative unit to measure this radiation --- the REM. REM means Roentgen Equivalent Man. For example, if an individual were to receive a dose of 400-500 REM, this amount of radiation is sufficient to cause death to 50% of the human beings being exposed. Death will probably occur within the first 30 days after the exposure. This is referred to as the LD 50/30; the amount of radiation which would kill 50% of those exposed within 30 days. If you received greater than 800 rem, the probability of death is much higher. On the other hand, lesser amounts, say 100 or so rem may result in noticeable radiation sickness, vomiting, change in white and red blood cell count, temporary sterility and the like, but depending on the health, age and mental well being of the patient, the probability of recovery is quite high. Very small amounts may be sufficient to trigger cataracts, leu-

kemia, tumors, etc., years after the exposure. To summarize, when you drive on a highway the unit of measure is miles per hour and when you describe radiation the unit of measure is REM. Like driving, the higher the value the greater the chance for severe consequences.

The levels of radiation I have been talking about up until this point are quite large and are not amounts that we could expect to receive from our natural radiation environment. Therefore, let's divide the radiation unit REM by 1,000 and call it a millirem. Now we are down into an area where we can establish a dialogue with the NATURAL RADIATION ENVIRONMENT. This is the radiation we are receiving from our solar system and radioactive materials present on earth. Many radioactive materials are ubiquitous, present in greater or lesser amounts in soil, building materials, food, air and living organisms and species. Many of the radionuclides, such as uranium and thorium, decay to daughter products which are also radioactive.

Let's take a look at a few specific radioactive materials. The lightest is tritium--it is an isotope of hydrogen. The nucleus of the tritium atom is composed of one proton and two neutrons. Here we see a situation where "two is company, three is a crowd." We have an unstable condition similar to that which I described earlier (husband, wife and lover). Tritium decays with a half-life of 12 years. The half-life of a radioactive material is that amount of time necessary to reduce the quantity of that material to one-half its original value. Tritium is produced by cosmic ray interactions with our atmosphere and today it has reached a steady state. Tritium is also produced and released to the environment from nuclear weapons detonations (above ground) and to a much lesser extent from nuclear power plants. Potassium-40 is

a radioactive isotope of potassium which is created by cosmic ray interactions with our atmosphere and so is carbon-14. We'll talk more about these later. Uranium and thorium have been present since the world was created. Uranium, in particular, is being used as a source of nuclear energy. It is the 8th most abundant element and is presently being mined in several areas. It is also being extracted and sold as a by-product from the superphosphate fertilizer industry and the copper mining industry. Thorium is present in beach sands. These are but a few of radioactive materials found in nature. Man has produced new materials as well as added to the total amounts of naturally occurring radioactive materials. To see how much radiation we get from the different sources, please refer to the first slide which represents a summary of our Personal Radiation Inventory for one year.

Item #1. The first source of radiation is cosmic radiation. The preponderance of cosmic radiation comes from the sun; about 85% of it is protons, 11% alpha particles, and the remainder nuclei of larger materials. Cosmic radiation, of course, increases during periods of solar flares and decreases during periods of solar inactivity. This tends to follow an 11 year cycle. The cosmic radiation strikes the upper atmosphere and is attenuated. However, the attenuation interactions produce neutrons, mesons, beta particles, gamma radiation, etc. The average energy of cosmic radiation is about 10^4 million electron volts (MeV); the maximum energy is about 10^{13} MeV. The closer one is to sea level, the more atmospheric shielding is above your head and, therefore, the smaller the actual dose of radiation you receive. The sea level amount is 40 mrem. While I was in the submarine program, the radiation levels we received while cruising 100 feet or so below the

surface was about nil. The water provided additional shielding from the cosmic radiation. If we look at Tempe, Arizona, which is 1000 feet above sea level, we see that the radiation level has increased about 10 additional mrem. If you live in an area of high elevation, the radiation level will be increased accordingly. Thus, we can see that there are fluctuations in our radiation inventory based on the altitude of our domicile. If we spend periods of time at different elevations, the radiation dosage should be adjusted accordingly. Moving from the equator to either pole will also have an effect on the amount of radiation received - being higher toward the poles. I will defer discussion on doses received by those flying commercial jets until Item 5. Incidentally, as mentioned earlier, some of the cosmic ray interactions with the atmosphere produce radioactive products, such as potassium-40, tritium and carbon-14. Potassium-40 and carbon-14, in particular, have a certain uptake in retention in living species and will be discussed later. Calculate your radiation dose and insert it in the blank provided.

Item #2. The next area that needs to be considered is home construction. Building materials contain trace amounts of radioactivity, lesser amounts being in wood, for example, than concrete or brick. Granite structures seem to contain the largest concentration of radioactive materials and there are also considerable amounts in gypsum wall-board. Some gypsum is a by-product of the phosphate fertilizer industry. Phosphate fertilizers contain trace amounts of uranium and radium. During separation the uranium tends to collect with the phosphate and the radium concentrates in the gypsum. With respect to granite, Grand Central Station in Manhattan, New York, would probably break the law if it were a nuclear plant because the radioactivity in its granite blocks exceed the Nuclear

Regulatory Commission standards. This is, however, radiation from our natural environment. Water coming from wells drilled into the granite basins of New Hampshire and Vermont often contains excessive levels of radioactivity.

Item #3. This leads us into our third item - Water and Food. We can see the U. S. average is 25 mrem and note that, by golly, there are some trace amounts of radioactive materials in the food and beverages we consume. Some materials contain larger amounts of radiation than others. Cereals tend to have higher concentrations of radioactivity and so do nuts, particularly Brazil nuts. Note that if you are a "pack-a-day" smoker, you need to add 30 mrem. If you smoke more or less than a pack-a-day adjust the radiation dose accordingly. Studies have indicated there is a direct relation between the radiation in tobacco and upper bronchial lung carcinoma. Where does this radiation come from? It's plutonium-210, a natural occurring daughter product in the uranium decay chain. Somehow tobacco has a propensity for the uptake and retention of polonium and it is not removed during the curing and manufacturing process. So, when you smoke, in goes the radioactivity and if this doesn't cause cancer in the upper bronchial regions, I submit that chemical carcinogens will get you in the lower bronchial area. Incidentally, studies of uranium miners revealed that there is a slight increase in lung cancers. However, if the uranium miner smokes, the incidence of lung cancer is strikingly higher. Even those who imbibe are not free from radiation. Note the relationship between beer and radiation dose. Well, for those of you who say, "I don't drink beer, I go for the hard stuff," it turns out that the radiation dose may be even higher.

Item #4. The decay of naturally occurring radioactive materials produces gases such as radon which diffuse from the ground into the atmosphere and provide a certain amount to the yearly dose. On the average in the U. S. it's about 5 mrem.

Weapon testing, that is to say, above ground ~~nuclear~~ testing which was conducted by several countries during the past two decades, is contributing an additional 2 mrem per year. The levels were higher during the period of testing, but is now decaying off because many countries have committed themselves to a ban on surface testing of nuclear weapons. However, because the French and Chinese still conduct occasional surface nuclear detonations, the level will not decrease much more until they join the ban.

Item #5. Observe the radiation received aboard a trans-continental flight. For a normal flight, add 4 mrem for each 5,000 miles traveled. We have confirmed this with an independent, non-funded study by the ASU Radiation Research Laboratory. The radiation is coming from cosmic rays and attendant interactions. The higher the altitude, the greater the radiation dose. A recent magazine article mentioned radiation and supersonic commuting. "The aeromedical specialist warned that speeding along at an altitude between 50,000 and 60,000 feet, the human body can withstand only 61 transatlantic round trips a year. It is not a matter of jet lag. Just the galactic radiation." I can not comment on this because we have not been permitted to monitor high flying, supersonic aircraft.

There has been some concern about carrying radioactive materials aboard commercial aircraft. However, the current regulations and statutes are sufficiently stringent to prohibit passengers from receiving any radiation from radioactive cargo. Thus, the principal contribution from flying is cosmic radiation.

Item #6. Check your wristwatch. If it was manufactured a decade or more ago and it has a luminous dial, then chances are it is a radium dial watch. We have a geiger counter in the lobby and if in doubt, I suggest you use it to check the radiation level of your watch. There is a certain amount of radiation being emitted from this type of watch and you should add the contribution to your inventory. I use radium dial wristwatches as check sources in the radiation laboratory. New watches use tritium or promethium-147 and their radioactive decay does not release any radiation which escapes from the watch.

Item #7. There is a small amount of radiation being emitted from television sets, particularly the older color TVs. If you sit very close to the set, you may want to add a bit more radiation to your inventory.

Item #8. The amount of radioactivity in the human body comes from several sources. Cosmic ray production of potassium-40 and subsequent ingestion and retention in the body doses you with a certain amount of radiation. A portion of this radiation is emitted by your body. So, if you sleep with a spouse, lover, and/or all of the above, you are dosing your friends and your friends are dosing you. Add up whatever you feel is necessary and insert in the box provided.

In addition, the body has a certain steady state concentration of carbon-14. This is naturally occurring and produced by cosmic ray interactions. Before the increase utilization of fossil fuels, there was a steady state level of carbon-14 in the environment. This provided mechanism for dating fossil remains. During life, one breaths carbon dioxide to which a very small amount contains radioactive carbon. The body achieves a steady state quantity of the radioactive material but when

you die, you no longer ingest the material and what is in your body begins to decay. Knowing the level in the body at the time of death and the rate at which carbon-14 decays, researchers are able to work backwards in determining the age of specie. Carbon dating is very difficult, time-consuming and has a considerable amount of error. Man has added to the error by releasing the emissions from fossil fuel plants. Fossil fuels are so old that all the radioactive carbon-14 has decayed. Therefore, the emissions from fossil fuel plants contain non-radioactive carbon. Assay of plants and other living organisms found in the vicinity of large fossil fuel power stations has revealed that the carbon-14 levels are perhaps 5 to 20% lower than levels in similar materials growing away from the power plant. The phenomenon is called the Suess effect. This is not to say that you can reduce your radiation level by living next to a fossil fuel power plant because there are other types of radioactive materials in fossil fuels. We will cover this in Item 10.

Item #9. This is the area which concerns me the most; medical and dental diagnostic x-rays. You can see what the average is in the United States, 55 mrem. Use this quantity or tally up the dose from individual x-rays which you have received during the course of the year. Notice that the levels can be quite high. European countries, particularly Great Britain, have reduced the average dose significantly by improving x-ray equipment and procedures. To illustrate the point further, it is predicted that around the year 2000, there will be about 400 times more cancer deaths (if we have not been able to cure cancer) attributed to medical x-rays than from radiation linked to nuclear power plants. These figures should be considered as guesstimates, an indication of the fact that we should reduce unnecessary x-rays and continue to improve x-ray

equipment. To obtain better information on dental x-rays, we conducted a series of experiments with the help of local dentists. We constructed a plastic phantom and his (her) picture appears in Slide #2. We obtained a skull from the anthropology department, glued in the missing teeth, and encased the skull in plastic. Slide #3 shows the phantom after shaping (with a body grinder). The head was sliced and holes drilled in several locations as shown in Slide #4. Into the holes we placed a radiation detector called a thermoluminescent dosimeter. They are very small crystals as shown in Slide #5. Radiation alters these crystals and by electronic and thermoluminescent techniques we are able to measure the amount of radiation received by the crystal. The head is packed with several hundred crystal detectors and taken to the dentist office. It is then set up for an x-ray as shown in Slide #6. This is a Panorex unit which takes a full face x-ray such as the one shown in Slide #7. The unit goes around the back of the head while the film is rotated in front of the head. The unit stops as it passes the spinal column in order to minimize radiation to that region. Because of the potential for tumors, cancer, leukemia, cataracts, etc., the areas we are concerned with are the thyroid, lymph nodes, mastoid and eyes. A Ritter x-ray unit which another dentist was using to obtain a full face set of x-rays was used in another test. Thus, it was possible to survey two different units and two different techniques. The Panorex takes one face x-ray as it rotates around the head, while the Ritter unit requires approximately 20 x-rays to obtain the same information. The radiation levels to the thyroid, lower teeth, upper teeth and eye level are presented in Slides #8 through #10. The units of radiation are mR or milliroentgen. They are sufficiently similar to millirem and we will not belabor the differences. At this time,

you will notice that the Ritter unit produces quite high levels of radiation to the front of the face. However, the benefits of information obtained by diagnostic x-ray facilities should be weighed against the risks. Furthermore, in calculating the radiation dose, the pinpoint radiation received to the face needs to be extrapolated over the entire body. I do not suggest prohibiting the use of x-rays because of the radiation levels present, but do suggest that indiscriminatory use of x-rays and excessive numbers of x-rays be stopped.

Item #10. If you live in the vicinity of a large coal-fired power plant, you want to add a bit of radiation. Trace amounts of radioactive uranium and radium are released during the burning of coal. The exact amount depends on the area from which the coal is mined. Studies have indicated that the amount of radiation released from a coal plant is greater than that released from a comparable size pressurized water reactor plant, but less than that released from the boiling water nuclear plant. In all cases, the levels are minute. There is very little, if any, radioactivity in oil and virtually none in natural gas.

Item #11. As Steve Rogers pointed out yesterday, there can be measurable amounts of radiation released from a geothermal facility depending on the location of the basin. Our studies of Arizona hot springs indicated that not only are there very limited geothermal resources, but also it is not very radioactive. Geothermal radiation levels are currently being assessed by the Environmental Protection Agency.

Item #12. There are legal limits to the amount of radiation one can receive at the boundary of a nuclear power station. If you spend your entire life at the boundary fence, eat the food grown at the fence, drink the milk from a cow who grazed at the fence and eat fish, etc. and other

meats that were produced at the boundary, you will receive no more than 5 mrem in a given year. This can be extrapolated to various distances from the site. In general, however, the U.S. population received about 0.01 mrem in 1973 and this will probably increase to 0.1 mrem by the year 2000. Other facilities, such as processing plants, may increase the levels slightly.

What I suggest you do now is total yearly inventory of radiation and see how you compare with the average. Note the major and minor sources of radiation and recognize that the principal mechanisms available to reduce your radiation exposure are (1) minimize the domicile elevation and (2) minimize the number of medical and dental x-rays.

I hope this provides a perspective on our natural radiation environment as well as a means to understand the sources of radiation and the amount that we receive.

QUESTIONS

1. What is the rate of radiation retention if, for example, you had a spinal x-ray four years ago?

I would like to defer a specific answer to that question until Jerry Cosgrove's presentation. He is competent to answer that type of question and I don't feel qualified to go into it in detail. Speaking in generalities, however, radiation dosage is cumulative. However, if it is received in small amounts over a long period of time, the body can repair some of the damage and rectify many of the injured or dead cells. Needless to say, you have insulted the system and there will not be total restitution. In addition, you might set off a chain of events which could trigger a wild multiplication of cells, or cancer.

2. Do we receive much radiation from x-ray scanning units at airports?

No, the levels of radiation emitted by these units are sufficiently low and we need not consider them. Besides, if you are flying for a considerable time at high altitude the preponderance of radiation will come from cosmic sources and any x-ray scanning contribution

to the dose received during the trip would be negligible. Flight attendants are concerned about the radiation levels received because they work long hours at high altitudes. A ball park figure for flight attendants and pilots might be around 500 additional mrem per year. The female flight attendants have cited large numbers of abnormal pregnancies and want to determine the cause. I feel this problem is not the result of radiation but probably other stresses associated with their particular occupation.

3. Are you aware that during the era of significant above ground nuclear weapons testing, aircraft flying at high altitudes often times had to be decontaminated because of the global fall out on to the aircraft?

No, I wasn't aware of this.

4. What are the radiation levels aboard the nuclear submarines?

The radiation levels aboard nuclear subs are significantly less than you would find, for example, in New York City. First, the water separating the sub from the surface provides an excellent shielding from cosmic radiation. Second, the nuclear reactor is adequately shielded to minimize radiation levels and third, the living quarters on nuclear submarines are at the front of the vessel while the reactor plant is at the rear, providing physical separation which is another measure of protection. Time spent near the reactor compartment itself was, of course, minimized.

5. How do fluoroscopes compare with x-ray units?

If you want to assume certain things, they are approximately equal. However, some of the fluoroscopic exams and cardiovascular exams deliver very high doses to the patient. I think the regulations state that the maximum dose delivered to the table top of the fluoroscopic unit cannot exceed around 10,000 mrem per minute. But remember that benefit vs. risk must be considered in discussing medical radiation sources.

6. People are saying radiation is extremely dangerous and thousands will die from cancer unless nuclear power is halted. Is this valid?

It depends on who you read and how they chose to manipulate the data. Take a good look at the qualifications of the individual making the statement, the study being quoted, what they are trying to show, the objectives they are trying to achieve, and if there are any obvious or subtle biases on the part of the individual -- then make your own judgment. We see no evidence that today's radiation levels are causing a problem. You have to remember that man has grown and survived in an environment that has been very hostile and in many respects has been exposed to radiation

in various amounts. From our previous discussion and noting the sources of radiation, we see that man is not really perturbing it significantly. I have not addressed an accident situation in a nuclear power plant and will prefer to defer that question to another time. People have been studying radiation and trying to understand its effects since man first discovered radiation. In the early days, individuals lost their lives, having handled radioactive material in an improper manner. Madame Curie, for example, is one who died of cancer, the result of improperly handling radium. As we continue to obtain more and more information, we adjust our philosophy accordingly. Radiation has probably been studied more and more is known about it than any other potential problem confronting mankind. The levels that man is allowed to receive are consistent with an extremely conservative and safe philosophy and the amount of radiation you receive from man-made sources is not statistically significant when compared against that received from the natural radiation environment.

A recently released study compared cancer incidence against domicile elevation. The inference was that the higher the elevation, the higher the cosmic radiation dose and perhaps, the higher the incidence of cancer. The results were just the opposite. The higher the elevation, the lower the cancer incidence.

An interesting story about the evolution of the weapons program and plutonium goes back to World War II. When the first amount of plutonium was manufactured, half of it went to the weapons people and the other half went to the biologists. Much to the dismay of those responsible for the defense of the country, who wanted the plutonium for a bomb, those in positions of responsibility recognized that plutonium might be a very hazardous material and insisted that health and safety research commence immediately. Again, I don't advocate getting any more radiation than necessary, but when the decisions have to be made, weigh all the evidence and see if the benefits are going to out-weigh the risks.

7. Are you monitored for radiation?

Yes, we in the nuclear industry and those who have occupations dealing with radiation are continuously monitored and records kept. To date, my record indicates I have received about 130 mrem in my 11 years in the nuclear industry. In 11 years, I got less from my occupation than I get in one year from the natural radiation environment. However, in our business, caution is the word of the day. We strive to be very, very conservative and very, very careful. Incidentally, medical doses are not included in occupation radiation records.

8. Do nuclear submarines discharge radioactive waste in harbors?

They did during the early days of the nuclear submarine program. However, as soon as small levels of radioactivity were detected in the harbors, this practice was terminated. As a matter of fact, it is prohibited by law to discharge within about 12 miles of land. Radioactive materials are still dumped in the ocean. Some countries use the ocean as a garbage dump more than others. I'm not advocating that dilution is the solution to pollution and I don't agree with the philosophy. I'm merely pointing out that this is happening. This is an area that needs attention.

I'd like to move now into a discussion of fission theory which will be covered by our next speaker.

PERSONAL RADIATION INVENTORY
(YEARLY DOSE)

SLIDE #1

SOURCE OF RADIATION	mrem/year
1. Cosmic Radiation:	
40 mrem at sea level	
(Add 1 mrem for each 100 feet elevation)	
Tempe (about 1000' = (40 + 10.0) mrem)	_____
2. House Construction:	
Wood 35 mrem	
Concrete 50 mrem	
Brick 75 mrem	_____
3. Water and Food:	
a. U.S. Average	25
b. Heavy Smoker (add 30 mrem)	_____
c. Drink Beer (add 1 mrem for each 100 bottles)	_____
4. Air:	
a. Natural - U.S. Average	5
b. Weapons Testing	2
5. Transcontinental Flights:	
Add 4 mrem for each 5000 miles in flight	_____
6. Radium Dial Wrist Watch: (add 2 mrem)	_____
7. Television : U.S. Average	2
8. Radioactivity in Human Body:	
a. Dose to yourself (⁴⁰ K)	20
b. Sleep with spouse (⁴⁰ K) (add 0.3 mrem)	_____
c. Dose to yourself (¹⁴ C)	0.2
9. Medical and Dental Diagnosis:	
a. U.S. Average 55 mrem or	
b. For each chest, teeth, head, neck and bone x-ray, add 20 mrem	
c. For each spinal column and kidney x-ray, add 200 mrem	
d. For each stomach, intestines and gall bladder x-ray, add 250 mrem	_____
10. Live in Vicinity of Large Coal-Fired Power Plant (add 0.1 mrem)	_____
11. Live in Vicinity of Large Geothermal Power Plant (add 1 to 100 mrem)	_____
12. Nuclear Power Plants:	
a. If you live	
(1) At boundary fence (fraction of year spent at location multiplied by 5 mrem*)	_____
(2) One mile away (fraction of year spent at location multiplied by 0.5 mrem)	_____
(3) Five miles away (fraction of year spent at location multiplied by 0.05 mrem)	_____
b. General U.S. Population:	
Add 0.01 mrem for 1973.	_____
TOTAL	_____ mrem/year**

*The plant(s) design basis is 1% of permissible. The average dose to nearest neighbor is expected to average less than 1 mrem per year.

**Average dose in U.S. is about 150-250 mrem/year. For comparison, average lethal dose to humans is about 400,000 mrem, received instantaneously.



Slide
#2



Slide #3



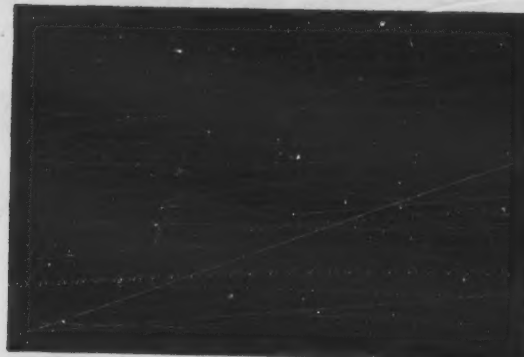
Slide
#4



slide
#5



Slide #6



Slide #7

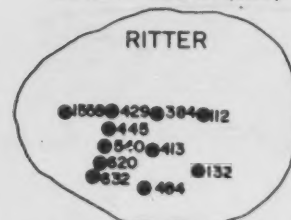
THYROID (mR)



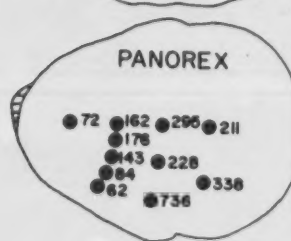
Slide
#8



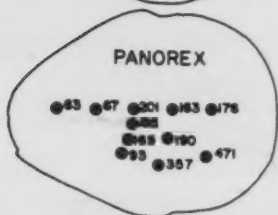
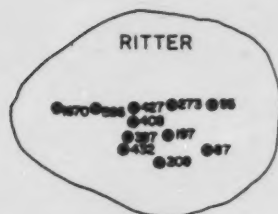
LOWER TEETH (mR)



Slide
#9

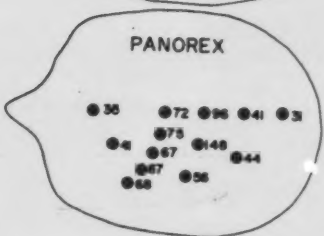
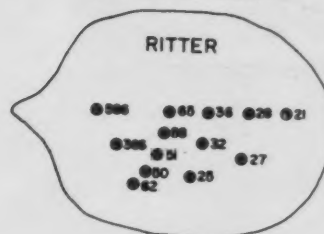


UPPER TEETH (mR)



Slide
#10

EYE LEVEL (mR)



Slide
#11

FISSION THEORY

By
DR. JOHN BREGAR

**College of Engineering Sciences (Nuclear)
Arizona State University
Tempe, Arizona 85281**

FISSION THEORY

Nuclear Structure

We begin with the assumption that all matter is comprised of three basic building blocks; protons, neutrons, and electrons. Atoms consist of a central nucleus composed of protons and neutrons surrounded by a cloud of electrons.

Protons and neutrons have about the same mass. Protons contain a single positive charge while neutrons have no charge. Electrons are very much smaller than protons and neutrons and carry a single negative charge. We specify the mass of these particles in atomic mass units or " μ ". One μ is defined as 1/12 the mass of a carbon atom. (Slide 1)

$$1\mu = 1.6 \times 10^{-27} \text{ kilogram}$$

On this basis...

$$\text{Proton} = 1.007277\mu$$

$$\text{Neutron} = 1.008665\mu$$

$$\text{Electron} = 0.0005486\mu$$

Suppose we had a supply of protons, neutrons and electrons. We could then assemble any kind of atom we please. We use a rotation system that tells us how many of what kind of particles will be needed. Note that the atomic number "Z" is the number of either protons or electrons. The chemical nature of an atom is determined almost entirely by the electron arrangement. The mass number "A" is the sum of the protons and neutrons (Slide 2).

As we assemble various kinds of atoms, we find that we must have about the same number of protons as neutrons; otherwise, the nucleus will be unstable. It is possible to assemble atoms with the same number of protons (Z number) but with a slightly different number of neutrons. Such atoms all belong to the same chemical family and would have virtually identical chemical properties. Since they differ only in the number of neutrons, such atoms are called isotopes (Slide 3).

Since we know the mass of individual protons, neutrons and electrons, it should be possible to calculate the mass of any atom by adding the mass of each particle making up the atom. Now a strange thing happens. The sum of the parts is greater than the sum of the whole. In other words, some how, in putting atoms together, some mass disappears. Likewise, should we try to take the atom apart, we would discover somehow mass appeared. This mass disappearance is called the "mass defect" (Slide 4).

Using Einstein's relation $E = MC^2$, we can calculate the energy equivalent of this mass defect. We call this the "Binding Energy". We can think of this Binding Energy as the energy holding the protons, neutrons and electrons together. We must provide energy to disassemble an atom and energy is released or created when the atom is assembled (Slide 5).

We can draw a very important conclusion. "Any nuclear reaction that results in a mass defect will release energy." (Slide 6)

There are two important classes of nuclear reactions that result in a mass defect, that is, will release energy. Fusion is the process in which light elements are "fused" together in just a way that some

mass will disappear. We will not go into the details of this process at this time, but only say that it is what many of us believe to be the energy production process of the 21st century. (Slide 7)

Fission is the process in which a heavy element is split into two parts. These fission fragments weigh less than the original atom so that mass disappears and energy is released. (Slide 8)

We can picture this process in terms of a liquid drop. Left alone, it assumes a spherical shape. Excite it a little and it will vibrate for a while but returns to its original state. Over excite it and it will split or fission into two or more drops or fragments. We can sufficiently excite certain heavy elements by causing them to absorb a neutron. (Slide 9)

Such materials can be used to support a chain reaction process. That is, the particles released in the fission process can cause a second atom to fission. In turn, that fission releases particles which causes another atom to fission. The requirements for a chain reacting system are: (Slide 10)

1. Material that will fission easily.
2. Fission process that will release energy.
3. Fission process that will release particle capable of causing other materials to fission.

We can illustrate this process by a cage filled with mousetraps with ping pong balls sitting on the mousetrap. If we drop a single ping pong ball into the cage, it will cause a mousetrap to snap (fission) which releases energy and hits another ping pong ball which in turn causes the process to continue.

There are only three materials that are of interest as practical fuels for such a chain reacting system: uranium 233, uranium 235, and plutonium 239.

The first and last do not exist in nature except in trace quantities. Uranium is an abundant element on earth but less than 1% is uranium-235. However, there are two elements that can be converted into either U-233 or Pu-239; these elements are thorium-232 and U-238, both rather abundant on earth. The process of changing the "fertile" materials into fissionable materials is called conversion or breeding. (Slide 11 & 12)

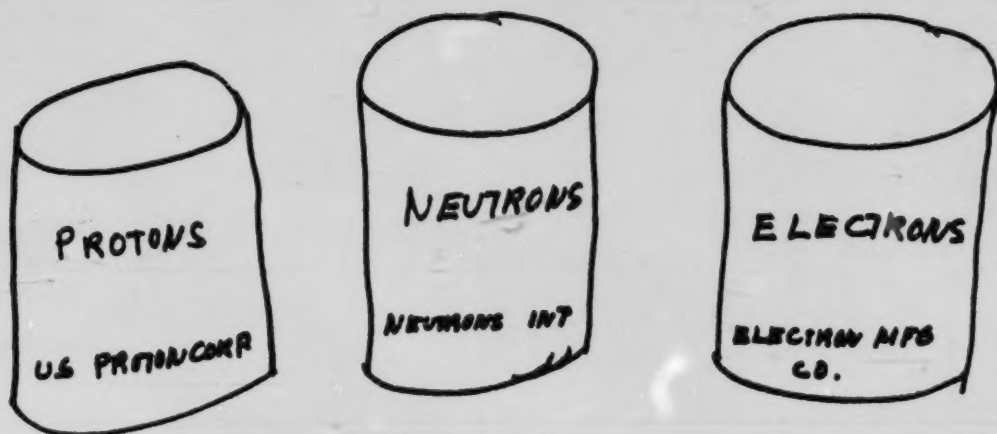
In summary, the fission process is capable of releasing large quantities of energy. This energy, in the form of heat, can be used to generate electricity. (Slide 13)

The basic process of using heat sources (coal, oil, gas or uranium) to produce heat; we illustrate the process in Slide 14 using a candle as a heat source. The heat is used to boil water to make steam. The steam drives a turbine-generator which produces electricity. The exhaust steam coming from the turbine must be condensed, then returned to the boiler to continue the process.

We can choose gas, oil or coal as the heat source. We burn these in a furnace to produce heat to make steam. Out of the stack we get water, carbon dioxide, carbon (soot), sulfur dioxide, nitrogen-oxygen compounds, and in the case of coal, fly ash. (Slide 15)

On the other hand, if we choose uranium, thorium or plutonium as fuels to produce heat, we get highly radioactive fission fragments. These are not released up a stack but are contained in the fuel elements and we must deal with this at the fuel reprocessing plant. Nuclear plants are clean only in the sense they do not discharge combustion products at the power plant. (Slide 16)

No matter what fuel we use, we must deal with these waste products in some way--we may discharge them into the atmosphere as we do with coal plants, or we may bury them in salt deposits or shoot waste materials into the sun, as is being proposed for reactor waste.



PROTON

MASS. 1.007277u

CHARGE +1

NEUTRON

MASS 1.008665u

CHARGE 0

ELECTRON

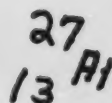
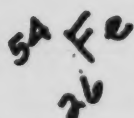
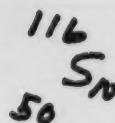
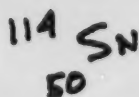
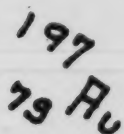
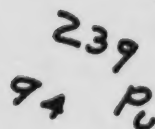
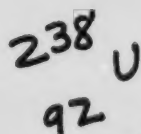
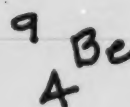
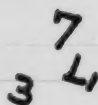
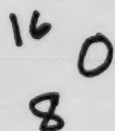
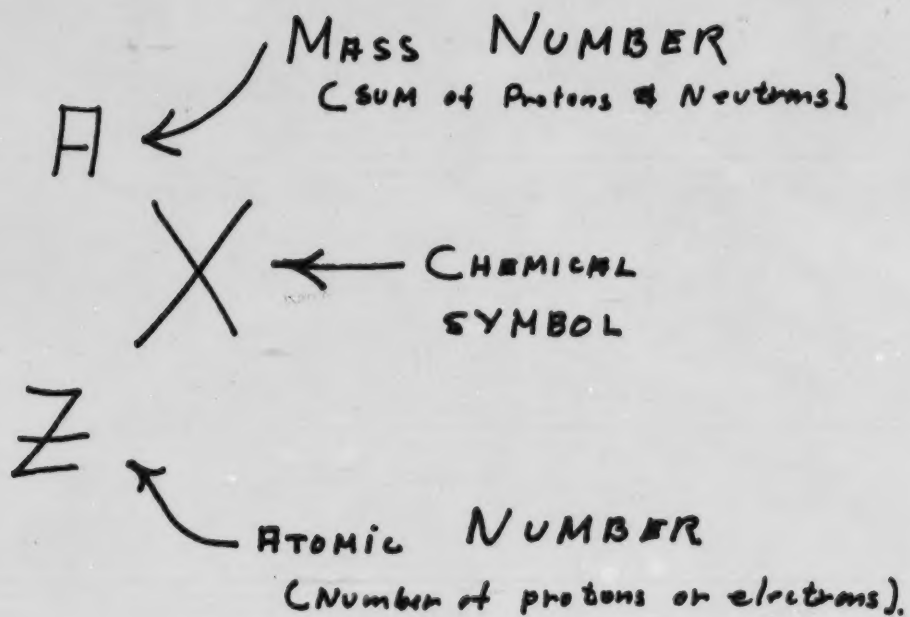
MASS 0.0005486u

CHARGE -1

1 u = 1 unified mass unit = $\frac{1}{12}$ mass of $^{12}_6\text{C}$

1 u is about 1.6×10^{-27} kilogram.

BASIC BUILDING BLOCKS.

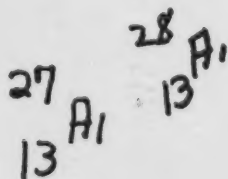
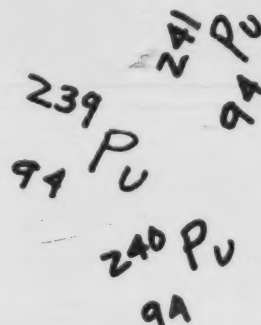
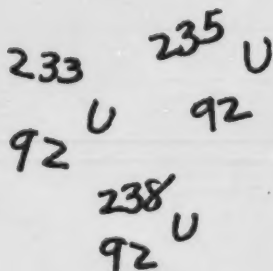
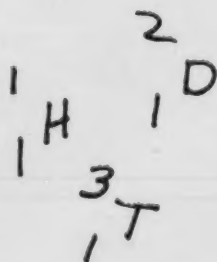
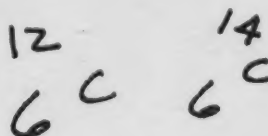
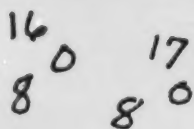
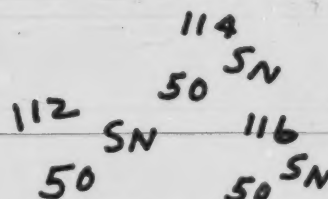
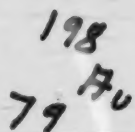
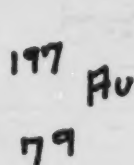


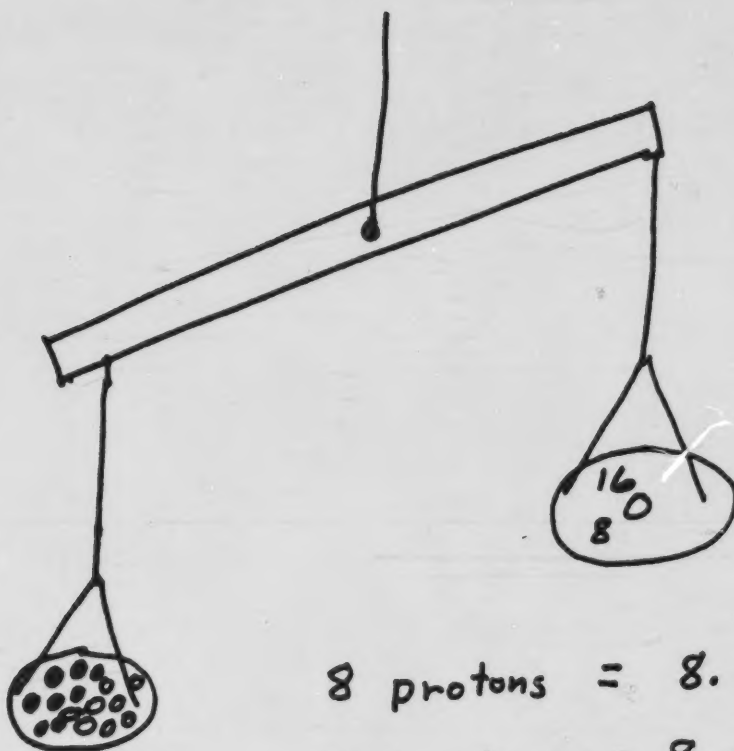
-223-

239

ISOTOPES

ATOMS THAT HAVE THE SAME NUMBER OF PROTONS (THUS THE SAME Z OR ATOMIC NUMBER) THEREFORE THE SAME CHEMICAL SYMBOL) BUT DIFFER IN THE NUMBER OF NEUTRONS





$$8 \text{ protons} = 8.058216 \mu$$

$$8 \text{ neutrons} = 8.069320 \mu$$

$$8 \text{ electrons} = 0.043888$$

$$\text{TOTAL} \quad 16.171424$$

$${}^{16}_8\text{O} = 15.994915$$

$$\text{MASS DEFECT} = 0.176509 \mu$$

$$\text{BINDING ENERGY} = 164 \text{ MeV}$$

about 10 MeV per particle.

$$E = M C^2$$

Allows us to calculate
the energy equivalent of
the mass defect.

ANY NUCLEAR

REACTION THAT RESULTS

IN A

MASS DEFECT

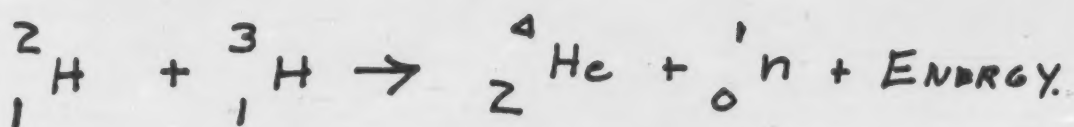
WILL

RELEASE

ENERGY

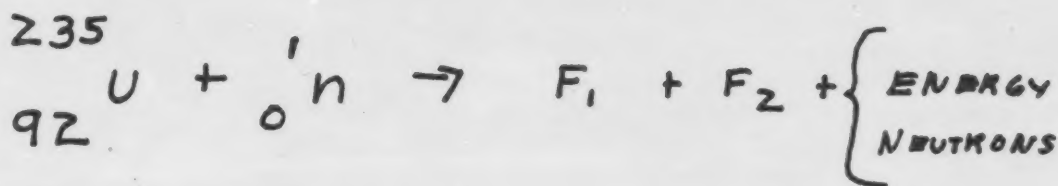
FUSION

A process in which
light elements are "fused"
together in such a way
that some mass will
disappear.



F I S S I O N

A process in which a heavy element is split into two parts. The fragments weigh less than the original atom so that mass disappears and energy is released.

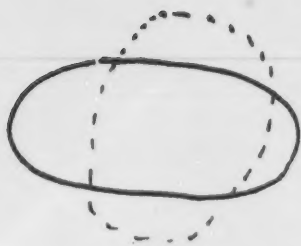


LIQUID DROP MODEL of

NUCLEAR FISSION.



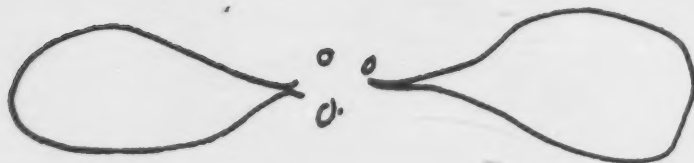
UNEXCITED
DROP



EXCITED
DROP



VERY
EXCITED
DROP



FISSION!

REQUIREMENTS FOR.

CHAIN REACTION SYSTEM.

1. MATERIAL THAT WILL FISSION EASILY.
2. FISSION PROCESS THAT WILL RELEASE ENERGY
3. FISSION PROCESS THAT WILL RELEASE PARTICLE CAPABLE OF CAUSING MORE FISSIONS

NUCLEAR FUELS.

FISSIONABLE

$^{233}_{92}\text{U}$

$^{235}_{92}\text{U}$

$^{239}_{94}\text{Pu}$

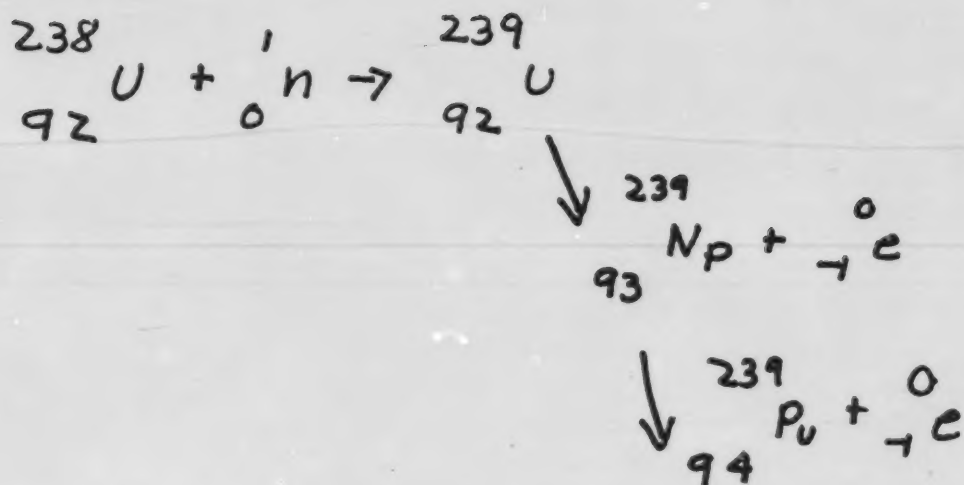
FERTILE

$^{232}_{90}\text{Th} \longrightarrow ^{233}_{92}\text{U}$

$^{238}_{92}\text{U} \longrightarrow ^{239}_{94}\text{Pu}$

CONVERSION and BREEDING

We can convert "fertile" materials into "fissionable" material.



If we can use Plutonium to support a chain reacting system and if we surround that system with Uranium ($^{238}_{92}\text{U}$) we can use unneeded neutrons to produce more Plutonium.

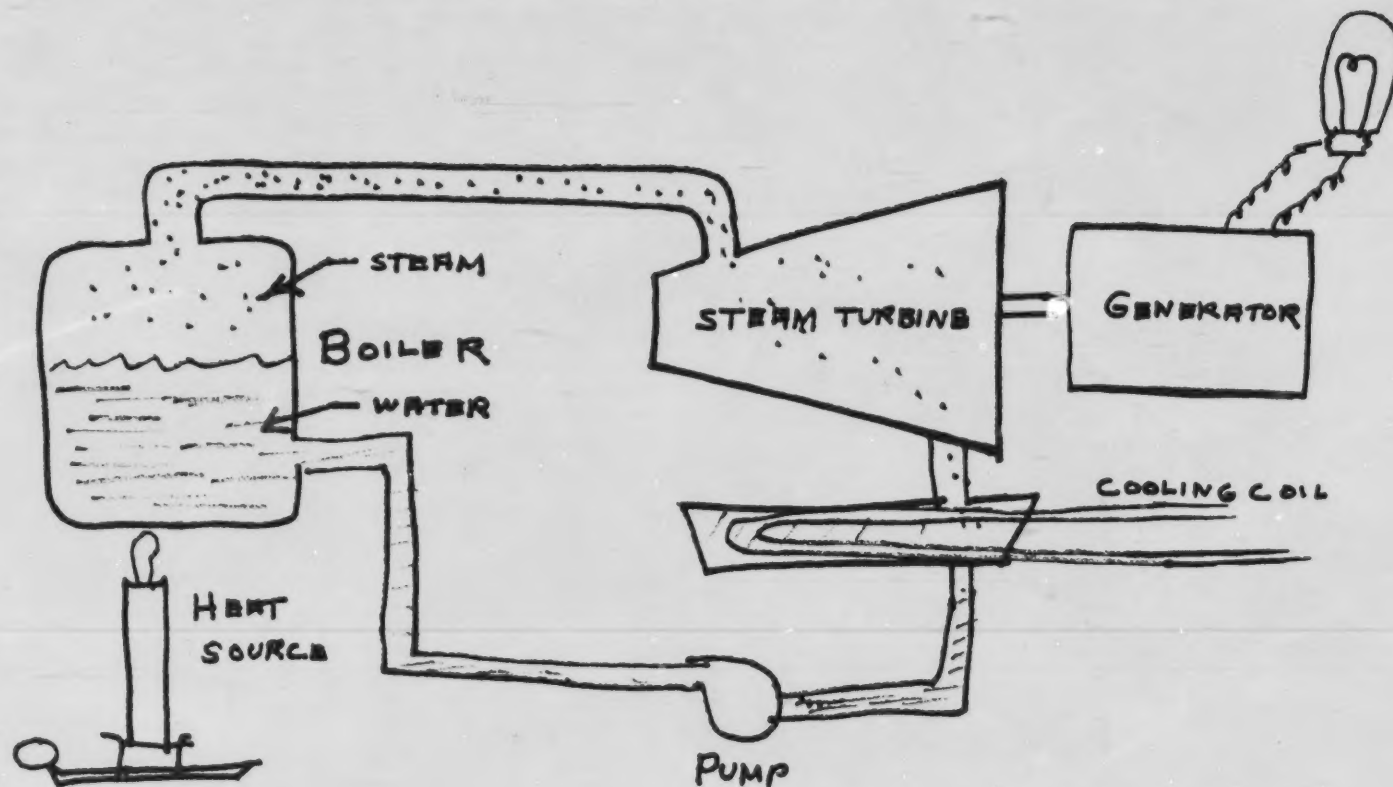
This is the basis of the "BREEDER"

SUMMARY

THE FISSION PROCESS IS
CAPABLE OF RELEASING LARGE
QUANTITIES OF ENERGY.

THIS ENERGY- RELEASED IN
THE FORM OF HEAT- CAN BE
USED TO GENERATE ELECTRICITY.

STEAM GENERATING SYSTEM



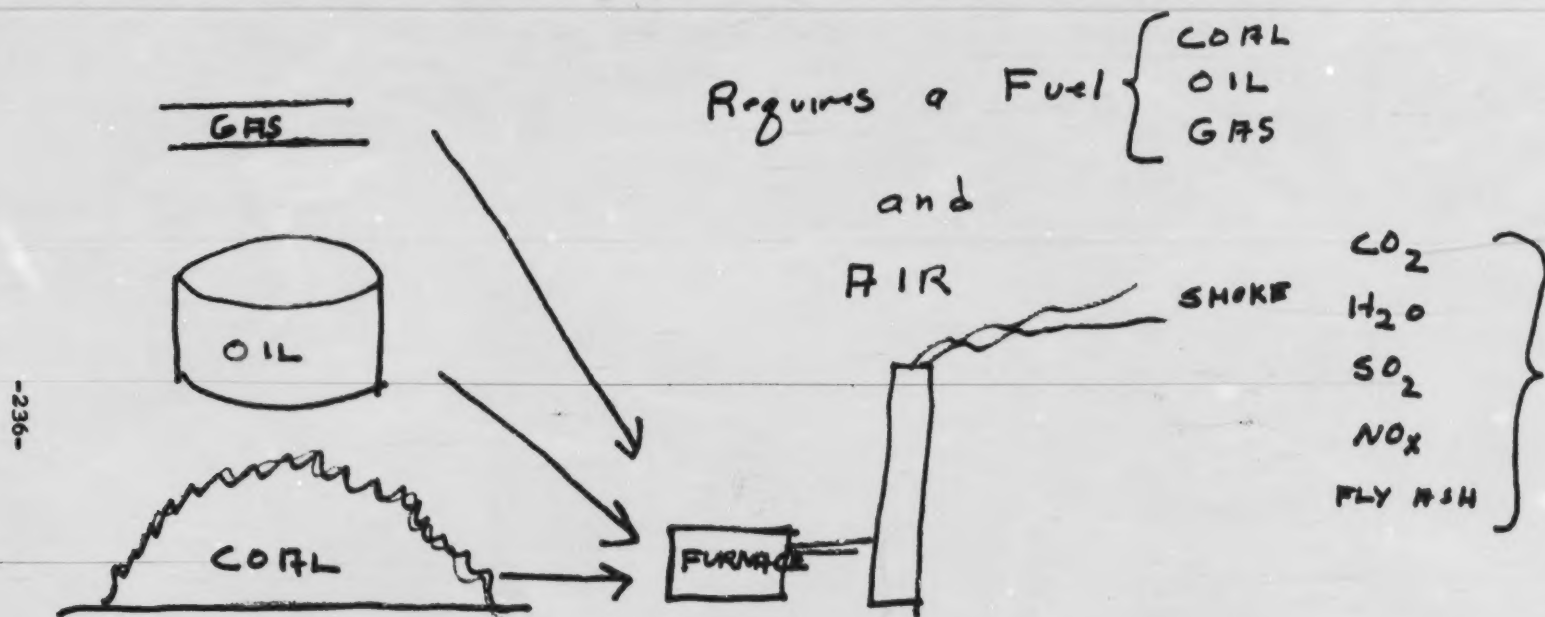
-235-

SLIDE 14

251

252

FOSSIL FUEL HEAT SOURCE



and Produces
Heat - to make steam.
Ashes (coal)
Combustion Products - (go up the
stack)

NUCLEAR HEAT SOURCE

Uranium

Plutonium

Thorium

FUELS



NUCLEAR
REACTOR

PRODUCES

HEAT - to make steam.

FISSION PRODUCTS

Highly radioactive

(but contained in

fuel element - not

released up the
stack.

Nuclear Reactors are "clean"
in the sense that they do not
require air, do not discharge combustion
products up a stack, but do produce a
~~very~~ large quantity of radioactive material.

-237-

SLIDE 16

ARIZONA'S PALO VERDE NUCLEAR GENERATION COMPLEX

**By
EDWIN VAN BRUNT**

**Director
Arizona Nuclear Power Project
Arizona Public Service Company
P.O. Box 21666, Sta. 3003
Phoenix, Arizona 85036**

ARIZONA'S PALO VERDE NUCLEAR GENERATION COMPLEX

It's really a pleasure to be here today. I heard both John McKlveen and John Bregar deny they were advocates. I'm afraid I can't do that but I'll try and stay away from it. John asked me to really tell you a little bit about the Palo Verde Nuclear Generating Station, give you a little description of the complex and tell you some of the unique things we believe we have incorporated into this design that you would find of interest.

You've heard quite a bit over the last couple of days about various energy sources ranging from conservation, gas, oil, geothermal, coal, and a lot of other things. What I'm going to tell you about is another energy source and how you take the theory that John Bregar gave you and turn it into physical hardware to generate electricity that keeps the lights on in your houses and really promotes growth in this country. I thought before I got into the details of the station, in about 2 or 3 minutes, I'd give you a thumbnail sketch of how the Arizona Nuclear Power Project came into being and what has transpired over the last four years since we got to work on this activity.

In about 1970, the energy crisis in general started to rear its ugly head in this country and the Arizona utilities responded to that. Arizona is a fuel barren state. There are some resources of fuel on Indian lands but as far as Arizona state land, that is, that available to private enterprise, it's really quite fuel barren. We don't have

any gas resources; we don't have any oil; and we don't have any coal. The Arizona utilities began to look at what were the other available resources that we have to generate electricity in the 1980's. In about the mid 1960's is when nuclear power came out of the development phase and came into commercial being. The first really large, what I would call commercial power stations, were sold in 1965. I think Oyster Creek was the first one, sold by General Electric Company to Jersey Central Power and Light. That station has been operating since about 1969 or 1970. Anyway, in 1970, the Arizona utilities formed a group called Arizona Nuclear Resource Study Group. This was made up of people from Arizona Public Service Company, Salt River Project and Tucson Gas and Electric Company. They were charged to look into nuclear energy as a viable alternative to gas and oil or coal to generate electricity in the 1980's. The result of that study which lasted over a year was that it appeared that nuclear provided a safe, economical, environmentally sound alternative to the other sources that we have available to us. Following that study, the managements of APS and Salt River Project, in late 1971, determined they would proceed with the development of a nuclear project. This is no small undertaking and in 1972, what is now the Arizona Nuclear Power Project was formed and came into being on April 1st. When we started out there were three of us: myself, Roger Robb, my assistant from Salt River Project, and another young engineer--with 2700 square feet of space and that was it. We didn't have any tables, chairs or anything else. We've spent a lot of money since that time.

In any case, following that we proceeded with site selection. The site for the project was determined in August of 1973 after about a

year and a half of study of the entire state of Arizona. The selection of the Palo Verde site was a balance of all the environmental and technical requirements that are related to siting a nuclear power plant. Also in about the same time frame, the two utilities APS (who was the project manager and operating agent) and Salt River Project were joined by four other utilities: El Paso Electric Company, Public Service Company in New Mexico, Arizona Electric Power Cooperative, and Tucson Gas & Electric. As you probably know, Tucson Gas & Electric sold their share in the project to Southern California Edison last August. We filed our application for a construction permit, which is a story in itself, with the Nuclear Regulatory Commission in July of 1974, less than two years ago. We had some hearings earlier this year in February before the Atomic Safety Licensing Board and were issued our construction permit for the three units of Palo Verde Nuclear Generating Station on May 25, 1976. These were not the only agencies we had to go before to get permits of one sort or another. We had to go before the State Siting Committee to get a Certificate of Environmental Compatibility here in the state to build the station as well as the transmission lines. We had to go through the Maricopa County Planning and Zoning Commission. We had to go through the Board of Supervisors and a myriad of other agencies and for each particular facility we build at the site, we have to get building permits just like anybody else would to build a home or anything else.

So, I think with that as a kind of background, I'd like to dive in and tell you a little bit about the Palo Verde site; tell you a little bit about the reactor system or what we call the nuclear steam supply system; tell you a little bit about something that everybody

seems to be interested in called the emergency core cooling system; and then tell you a little bit about some of what I think are unique aspects of this particular project, that to my knowledge you will not find in any project in this country. So, with that, I'll proceed with this discussion.

The Palo Verde Station (Slides #1 & #2) is located on a tract of land of about 4,000 acres which is about 35-36 miles west of the westerly most boundary of the City of Phoenix, about 3 miles south of the little crossroads called Wintersburg, Arizona. It's about 17 miles west of Buckeye, Arizona. The Southern Pacific Railroad runs about five miles to the south of the site. Buckeye-Salome Road runs about 3 miles north of the site and I-10 from Buckeye west to Tonopah and then on into Los Angeles is about 5 or 6 miles north of the site. The City of Phoenix is the nearest major population center. If you would go out to the site now you'd see a little more activity than in the past. Prior to receiving our construction permit the only activity that was there (or the only thing that you could see that would indicate there was going to be any activity) was a meteorological tower which went into operation in August of 1973 and has been collecting meteorological data since that time and will continue to collect data throughout the life of this plant. The data was used as part of our application to get a license. Slide #3 shows the site and is typical of the arid, desert environment. One of the unique aspects of this project is that we plan to use sewage effluent from the City of Phoenix 91st Sewage Treatment Plant to provide cooling water for our cooling towers which provide cooling for the condenser.

Slide #4 is the artist's rendering of one of the nuclear plants. The dome structure in the center is the containment building which will house the reactor and its primary support systems. These include the primary (reactor) coolant piping, pumps and steam generator where the heat is transferred from the reactor water to another, separate water supply. In the steam generator, the water is permitted to boil and the steam is piped to the turbine building and becomes the energy source for the electric generator. The turbine generator building is the large building on the right; it is approximately 320 feet long and 100 feet wide. The generator produces about 1170 MW of electricity, or enough to supply about a million people. The buildings to the left of the slide are auxiliary buildings and a fuel storage facility to support this particular unit. The other two units are identical.

Slide #5 illustrates the layout of the three-unit complex itself. Each unit is a separate entity and you can see it is layed out in a semi-circular array. The reasons the cooling towers are arranged in a cluster and the units are arranged in an arc is that prevailing winds on this site are in part of the day from the southwest to the northeast and the other part of the day from the northeast to the southwest. We are aligning the towers in this direction to keep the drift from the cooling towers from passing across the plant and messing up the transmission switchyards and streaking the buildings. Also, the circular arrangement is rather aesthetically pleasing and the colors of the buildings are representative of the name and general color scheme of the area. This enables the complex to blend well with the background. In the foreground is a 500 KV switchyard. The

administration building is between the switchyard and the middle nuclear unit.

In the administration building one thing we are going to do that is not unique to this plant but there are only a few utilities that have decided to proceed this way. One of the things you have to do when you get into operations is continually retrain your operators. Each year they must go back and take retraining and that retraining has to be done in a simulator. We ran a bunch of economic analyses-- you have several choices: you can build your own simulator, or you can send your people to another station that has a simulator, or you can send your operators to one of the reactor manufacturers who have a simulator for their system and train there. We found out that the economics weighed heavily in favor of building a simulator. So, we will have within our administration building a simulator where our reactor operators each year can go for training. This simulator is an identical mock-up of the control room in which they will operate each day. Through a computer associated with it you can feed in all kinds of perturbations in the operation of the plant and require these fellows to respond just like they were operating a power plant. This is a multi-million dollar facility in itself but we feel it is very beneficial and will result, we think, in a very high quality of training for the reactor operators.

Another facility I didn't point out when I was showing a previous slide is the guardhouse. Security for nuclear plants, as you probably read in the papers, is an item that gets quite a bit of attention. The site right now, the overall site of 4,000 acres, is fenced with four strand barbed wire fence and marked as no trespassing. The reactor

building itself will be fenced with a chain-link fence with barbed wire on top and the only way you can get in is through the guardhouse with badging and this kind of thing. Security for nuclear plants is very, very high on the list of things we have to deal with. The guardhouse in this facility is a very complex building in its own right.

One of the interesting things--the discussion John McKlveen had on doses from power plants. John indicated that the doses from nuclear plants must be less than 5 millirem each year and, in fact, the average dose from nuclear stations has been less than something like 0.01 millirem or that order of magnitude. When we were doing our calculations it seems that actually our controlling site boundary dose from this plant was not from the reactor station itself, but was from the discharges from the cooling tower. It seems that the hospitals in some of their isotope labs where they do their radiation therapy on people, discharge quite a bit of radioactive isotopes into the sewage system that you discharge your sewage into. In the processes that you do in the sewage treatment plants, you tend to concentrate that. We found through our monitoring programs that we actually ended up with the controlling dose at the site apparently coming from hospitals. The isotopes being released by the cooling towers and not from the station itself, which I think is rather interesting.

Now I would like to return to some of the basic reactor systems and talk a little bit about them.

Slide #6 is a schematic of a pressurized water reactor which is the type of system utilized in our electric generating station. This

system operates at about 2200 pounds of pressure and the temperature of the water is between 600° to 650°F. The water circulates through the reactor core where the uranium fissions to produce heat and then through the steam generator where the heat from the reactor water is transferred to the secondary side and comes off as steam. The steam goes through the turbine, is condensed in the condenser and the cycle is repeated. The amount of makeup for the cooling water of the condenser is that water which comes from the 91st Avenue Sewage Treatment Plant. In addition, makeup water for other systems comes from the ground water and amounts to about 100 gallons per minute. The amount being drawn off by wells will be less than that currently being used by farmers.

Slide #7 is a model of the combustion engineering nuclear steam supply system which we have purchased. The reactor is in the pressure vessel located in the center. You can see the inlet and outlet pipes going from the reactor to the massive steam generators on either side. To get an idea of the size, note the scale people standing above the reactor. The rods coming up the top of the reactor vessel are used to drive control rods in and out of the reactor. The control rods are made of boron, a material which absorbs neutrons and enables us to control the fission process.

Slide #8 is a more detailed diagram of the reactor vessel. Notice the dimensions and the mass of this particular component. The reactor itself is about 48 feet high and 15 feet or so inside diameter. The wall thickness is about 9 inches so you've got another 2 feet, roughly. Thus, the pressure vessel has an outside diameter of about 17 feet. The dry weight of this vessel is somewhere around 400 tons. The shipping of the vessel is a major problem.

The reactor vessel is dwarfed somewhat by the steam generator (Slide #9). It is a tremendously large piece of equipment--68 feet tall, 15 feet in diameter at the inner section, and 22 feet in diameter across the upper section. The weight of this vessel is approximately 700 tons; the heated water from the reactor passes through small tubes and the heat is transferred to the secondary water. As steam rises, it passes through the moisture separators and exits through the top of the generator.

Slide #10 shows the pressurizer. The pressurizer is one that controls the pressure on the reactor side. There is water in the bottom and steam bubble in the top. When the pressure starts to go up a little bit, you shut off heaters in the pressurizer. If it continues to go up, there is a sprayer on the top which sprays water down and quenches the steam bubble. Whenever the pressure gets too low the heaters in the pressurizer come on. This piece of equipment is about 42 feet tall and about $8\frac{1}{2}$ to 9 feet in diameter and weighs approximately 114 tons.

Let me just talk a minute about protecting against the worst case reactor accident called a loss of coolant accident to the reactor. A nuclear reactor will continue to generate heat even when it's shut down so we have to provide cooling. If, somehow, we were able to get a leak in this system large enough such that it became possible to uncover the core and not provide cooling, you would then have a problem on your hands. Now, there are any number of connections that you could see from some of the previous diagrams to the system that vary in size from maybe one inch instrument connections all the way up to the 42 inch main coolant pipes. Now, the worst leak you could get

is if somehow that particular pipe were cut in half. Now, pipes don't rupture that way. They don't just break in half like breaking a pencil or something. Historically, if you talk to metallurgists, a pipe will deform in some way. It will crack and start to leak in some way. The crack will propagate and finally, it will fail. Now, the other thing, if you remember, if you have a pipe going through my hands here. If somehow you broke it, even if I just pulled it apart, the amount of area for the water to flow out is relatively limited. We restrain these pipes so they can't move this way. In any case, when we get into this accident situation, we assume these pipes are going to move apart and we've got now what's called a double ended pipe break. We've got water running out of both ends of this 42 inch pipe line. And that's a lot of water running out, particularly when it's at 2200 pounds and the containment atmosphere is mainly an atmosphere of pressure. So, what we're trying to do now with the emergency core cooling system is if you get into this postulated accident, for which no mechanism exists, so that water is running out. Therefore, we have designed a system that will put water back into the reactor system and is intended to keep the core covered such that there will not be melting.

There are a number of components in this system. The first one are these safety injection tanks which are filled with water and under nitrogen or argon pressure, they are about 600 psi. We then have a system of pumps, three different kinds of pumps; two parallel systems. They are what are called the low pressure safety injection pump and the high pressure safety injection pump, and containment spray pumps. We also have some heat exchangers and this heat exchanger has another cooling loop and then another cooling loop which goes to emergency spray ponds.

Moreover, we've got a tank filled with 600,000 gallons of water and we've got a chemical storage tank that's filled with a boron solution which we can also put into the system to be sure the nuclear chain reaction does not continue. Now the sequence of events would be that you have some kind of accident and you have some kind of a leak. It's either a small pipe or big pipe. Now, you have to recognize that's the worst accident you could postulate and again, I have to point out that I don't know what the mechanism is that would cause it--this break, the double ended break of this 42 inch diameter pipe. In any case, the first thing that would happen, if you had that kind of a break, is that you would start to see a rise in containment pressures. Remember there is a containment building around the reactor system and you would be releasing a lot of water at high pressure and high temperature into the containment which would flash to steam. When it flashes to steam, the containment pressure begins to rise. Now, we have what is called a two out of four logic in our control systems. We have basically, for any particular parameter, four measuring points to bring those to a comparator. If we get on any particular parameter that we're measuring, in this particular case I'm talking containment pressure; if two out of those four sensors show there is an increase in containment pressure of 5 psi (containment is designed for some 60 psi), immediately the first thing that happens is that the low pressure and high pressure pumps start into operation and certain valves open. That means your system's ready to go. Now, if you are leaking water out, the pressure in the reactor system is going to go down. Also remember that the safety injection tanks are pressurized at about 600 pounds. As the pressure in the system comes down, water starts flowing in as the pressure from

the pumps or the pressure from the tanks over there. That water goes into the reactor system. Now, you say you've got this leak in the bottom so it's going to continue to leak out. Well, it does. Well, we have a reactor sump where the water as it leaks out goes into that sump and then at the point when that tank up there becomes empty you go into what's called a recirculation mode. You start recirculating and pump the water from the sump back through and you've now established a steady state system, so that you will continue to cool the reactor core when you have this postulated break. I have to go back again to the situation that I don't know what the mechanism is for this particular break.

Now, these systems are all redundant. They have redundant power supplies; we have redundant diesel generators; the control cables for them are redundant. You may have heard about the Brown's Ferry incident where there was a fire. In our particular situation, that could not happen or could not have the same effects in that we have separate cable spreading rooms for each of the redundant systems. We have an A system and a B system; the A systems come into the top of the control room and B systems come into the bottom and they never get mixed together. Therefore, if there is a fire in one, you won't have it in the other; and you can't knock out one system by the effects of the other. Piping is all separate. A great deal of effort is put into keeping these systems completely separate and redundant. The emergency core cooling system, while it has not been tested in actual reactor accident, has been tested in all of its modes of operation. The individual components are tested prior to shipment and as part of our pre-operational testing procedures, we will also test these systems. They

will be tested under their actual conditions. We will lower the pressure in the reactor system down to the point where they are to operate and we will then turn those systems on and inject the water. Be sure that the water can flow. We've done everything short of having an actual accident which, from my point of view, certainly seems to be proved. Well, enough on the emergency core cooling system.

QUESTIONS

1. You described the worst possible case that would cause this system to go into action. What is the minimal case where the emergency core cooling system would start working?

The minimal case where it would go into effect would be if you have a small pipe break. A small pipe break is not a major problem because you're not leaking out very much water. If one of these, say, one inch nozzles or half inch nozzles or some kind of instrumentation breaks for some reason. A small stream of water will come out and this system can very easily keep up with that until you can shut the reactor down and cool it to the point where you no longer have a flashing situation with steam. You can then isolate the systems involved--there are a number of ways we can isolate them and get them fixed--the leak or whatever it is and then go back to power. The small break is not a major problem. The big break is the one that the system is designed to take care of. There have been a number of occasions where instrumentation malfunctions got the signal that called for this system to operate and it wasn't necessary. To my knowledge, this system has never failed to operate as it was designed.

2. What is maximum design pressure inside the containment following the loss of coolant accident?

The containment under the worst condition that I described in the Palo Verde Station is designed for 60 psi.

3. What are some of the other interesting features that make the Palo Verde Complex unique?

As I indicated, we are using a Combustion Engineering system that's called standard nuclear steam supply system. Combustion Engineering has sold a number of these systems. They are all identical. This system has gone through the licensing process as an independent system from our application. It was under

review for over two years. At the end of last year, it was given what is called preliminary design approval by the Nuclear Regulatory Commission which meant it was licensed to be used in a nuclear power station such as the Palo Verde unit. Our application referenced to a document that's called CESSAR Combustion Engineering Standard Safety Analysis Report. You get into this business and you get into alphabet soup. In any case, we referenced that document and that was part of our application. We are, I believe, the first station to receive a license to construct utilizing a standard safety analysis report.

Another thing we are doing is, all of our units are identical. Notice there were three units. If you look at most of the earlier plants that are multiple units, you will find they share a number of systems. They share maybe the waste system; they may even share diesel generators. Our systems are completely independent: Unit 1 is completely independent of Unit 2; Unit 2 is completely independent from Unit 3. They all have their own safety systems and everything else, so if there was some kind of problem in one unit, it cannot spread to the other unit. The only systems they share are the water reservoir and some other maintenance related types of activities. Initially, I mentioned the idea of separation. This plant, I believe, is as far advanced as any plant in providing separation of safety related systems. As I indicated, we have separate cable spreading rooms for redundant systems. The cable chases to those rooms are separate, piping systems are separate. There is no way a malfunction in one system can have an adverse effect on another like system--it's just not physically possible. So, that's what we did in a particular unit and then you can have no interaction between units. This was one of the criticisms of the Brown's Ferry situation where the cable spreading rooms for units 1 and 2 were shared rooms, so that when you have a problem in one you have a problem in both.

Another thing we've used and I think probably to a greater advantage than anybody else is the model. It is a model of the containment vessel. Now, we have modeled every building for this plant. We have an eighth-inch scale model and we have a quarter-inch scale model. With the model, for example, you can see the reactor, the steam generator and all the piping--the piping is all color coded. Each system has its own colored pipe. If it is a safety-related system, it has a certain color and this kind of thing. One of the things we've used the model for--we've built a model of the cranes that we are going to use to install the reactor vessels. Installing a vessel that weighs 400 tons is no small job, particularly when you've got to lift it to about 180 feet up in the air and then move it horizontally about another 160 feet. Then drop it back down and get it located within a few thousandths of an inch. It's no small operation. So, we have built models of our cranes. We have actually run the installation procedures for the heavy equipment.

Another thing we are doing in this job is using these models. We are using them to make construction drawings. Each of the pipes on the model will have a little designator and that designator gives from a reference point the centerline location of that piece of pipe. Written on the side of it, it may say something north, something south or whatever. We then can photograph that and those are physical construction drawings. So this is saving significant money in manufacturing of equipment, particularly piping and the location of that equipment. Whenever they find an interference they put a little red star and it is amazing how many of those we've found. The model, which cost about half a million dollars, has probably paid for itself ten times over already in finding interferences and this kind of thing. You have to recognize that when you are building a plant that has something like 10 million feet of electrical cable, probably 5,000 different pieces of pipe, some 185,000 cubic feet of concrete, that you will run into interferences that get missed when you are checking. Of course, you have to fix those when the guy goes to build the plant.

Well, those are a couple of what I consider to be unique aspects of this particular plant as well as utilizing sewage effluent for coolant. As far as the future events are concerned, construction on the project has started as a result of receiving our construction permit. We would expect to be loading fuel for Unit 1 in November of 1981. The first unit going into commercial operation in May of 1982, the second following two years later, and the third following two years after that.

think, in conclusion, based on what I've heard here today and based on my knowledge, I would have to conclude they are as safe and environmentally sound and certain, as far as the Arizona utilities are concerned, provide us with an economic alternative to some of our other dwindling fuel supplies.

4. During the hearings in sworn testimony it was stated that we are importing uranium. Is that correct?

I can't comment. My recollection of the hearing, certainly I was under sworn testimony in that case and I don't know whether you are referring to my testimony or to our consultant's testimony. Okay, he might have been talking in a general way. As far as the particular uranium fuel supplies for our units are concerned at the present time, all the uranium (and we have uranium under contract through the year 2000) will come from domestic sources. The first nine reload batches for each unit will be coming from Anaconda's mines in Wyoming. The additional beyond that will be coming from Westinghouse who is contracting through those that, to my knowledge, will all be domestic supplies as well.

5. I saw an article in the press and I wonder sometimes how accurate they are. They were commenting on the efficiency in different sizes of plants operated by nuclear power. They said a small plant of 100 megawatts is not as efficient as 1000 megawatts. Now, is this true that the larger they are the more efficient they are or is that just somebody's gestimate?

As far as the efficiency is concerned, energy in versus energy out, there is no reason why a pressurized water reactor of 100 megawatts versus a pressurized water reactor of 1270 megawatts should be appreciably different. If you are talking about a pressurized water reactor of a thousand megawatts versus a high temperature gas cooled reactor of a 1000 megawatts--because of the steam pressure, it's more efficient. Pressurized water reactors are like about 32 or 33% efficient. The high temperature gas cooled reactor is like about maybe 40% efficient. I think what tends to happen is that people mix up a lot of terms. I think what you've been reading about is what we call the economics of scale--that on a unit cost basis per kilowatt output, that a larger unit such as the Palo Verde Station will have a lower installed cost than say a 100 megawatt unit. I can't quote you the numbers on a 100 megawatt unit because they don't make it anymore. But if I look at a 900 megawatt system in the same years, they would be talking roughly something like \$1100 per kilowatt installed. We're talking something like \$700-\$800 per kilowatt installed. This is what is called the economy of scale. It's because of the amount of material and this kind of thing. I think that's what you're talking about. Now, there are other things that they talk about which is capacity factor. This is utilization of the energy that comes out. Generally speaking, you will find that smaller generating stations, I don't care what kind they are--nuclear, fossil--would tend to have a higher capacity factor because they don't have as much equipment. Whereas a larger system has much more equipment and will have more room for malfunctions, maintenance and this kind of thing and it tends to have a lower capacity factor. So you have to balance off capacity factor degradation because the size versus the saving in size because of the economy of scale. And this is where you get into a discussion of what the balances are. Our goal is a capacity factor in excess of 75% and we're looking for availability of 90%. Now, you've got to recognize that when you use a reactor plant every year you're going to be down for at least six weeks to refuel. So, it's never possible to get a capacity factor of 100%. The best you could ever get, if you ran every other minute you have, is something like 87%. Also, there are system demands--you know we come down over a weekend because we don't need the energy. This is regarding the peak rather than some average working.

6. Again, I suppose one must be careful of the media, but recently I think it was three General Electric engineers that retired. Why?

I think the word is quit. Anyway, they are no longer with their

firm. Their reason is for safety and one can't help but wonder why three people with 127 years of combined experience in the field would sacrifice that much opportunity of a job in that way. I just wondered if this is a personal feeling with them or is there a justification for this? Okay, you brought this subject up; I was going to stay away from it for political aspects. I really can't say what motivated those G.E. engineers to quit; that's their own prerogative. However, the press has also covered that they did belong to a quasi religious organization who has set out as its goal--going back to the wheelbarrow--my boss likes to call it. They found the way to do that is to bring the energy industry to its knees. So, I would have to say there is maybe some credence to that influence upon it. On the other side of it, I would have to say that in the hearings in which these gentlemen have testified, that to my knowledge and as far as the industry is concerned, also the Nuclear Regulatory Commission, there are no malicious rays that have not been known for a long time and have not been dealt with on a continued basis. Additionally, as a proven thing anymore than three guys quitting, I would have to point out there are some 4,000 or more engineers at General Electric Company who are still at G.E. And there is a whole bigger industry of which I am one who has not quit. So, I don't know--I can't tell you what motivated these fellows. As far as I'm concerned, it didn't tell me anything that I wasn't aware of; that I did not know had been problems that are not being dealt with one way or another as far as the industry is concerned.

7. How long does it take to take those units off the line if the decision is made to take them off the line?

Well, it depends. If it is a planned decision to come off the line, it will probably come down slowly and take a couple of hours. The units are capable of coming off the line instantly, in a matter of microseconds, in what we call a scram mode. If we learn there is some problem or something or other, the control rods just stick in and the plant shuts down. The thing you have to concern yourself with there is the point that I raised before--that they continue to generate heat even though you shut them down. So, you've got to make provisions to take that either way.

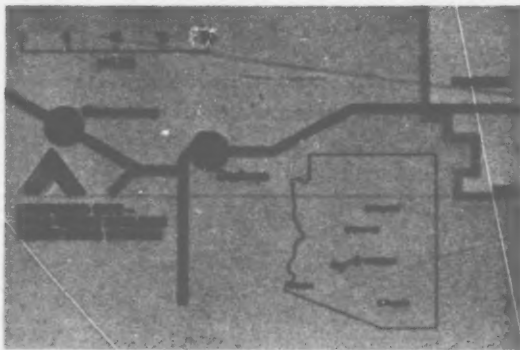
8. How long does that heat continue to generate?

For a long time. That's part of the waste situation--you have radioactive waste (really all radioactivity is energy), so you have radioactivity coming off and you have heat energy coming off and you have to make allowances for handling both of those. So, we cool with that shut-down cooling system I pointed out up here. We cool it for a period of time and then we move it. When we're refueling, for example, we take the fuel elements

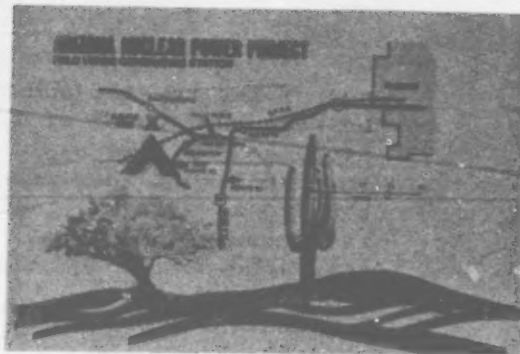
out of the reactor and move them under water so they both can be seen and cooled at the same time. From there to a fuel storage pool. We store them there for maybe six months and then we'll put them into cast which is designed to provide cooling as well as shielding and they get shipped away for reprocessing. But you always have to provide cooling for some long periods of time--also for shielding reasons.

9. What do you plan to do with the radioactive products that you get off?

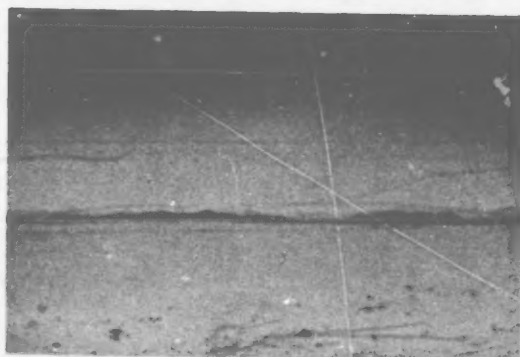
Well, the radioactive products you get from reactor plants are basically of two areas. You have a highly radioactive materials which are confined to the fuel elements themselves. Those fuel elements as I just indicated--you take those out and put them in a fuel pool until they are perfectly cool. You would then ship them to a reprocessing plant. I'll tell you, to be perfectly honest or somebody will call me about it if I don't, that right now there are no reprocessing plants in operation. There have been two in operation and operated satisfactorily. They went down to increase their capacity. They got caught up in a lot of the new concerns over plutonium, over security and this kind of thing, and right now they cannot get started up again. There's also a need for additional ones to get started and there are a number of firms who are interested in getting into this business. We will send them to that plant--the fuel elements will be chemically reprocessed, the still usable uranium will be stripped out, fabricated and reused. The plutonium would be stripped and presumably, if we are allowed to, we could then use it in a breeder reactor or something like that. The ashes, or the wastes, then go from that reprocessing plant to some ultimate storage which is the responsibility of the federal government. However, the federal government is obligated to provide that service since it's a long term proposition, the federal government can make the assumption that it's going to be here and they're going to take care of it.



Slide #1



Slide #2



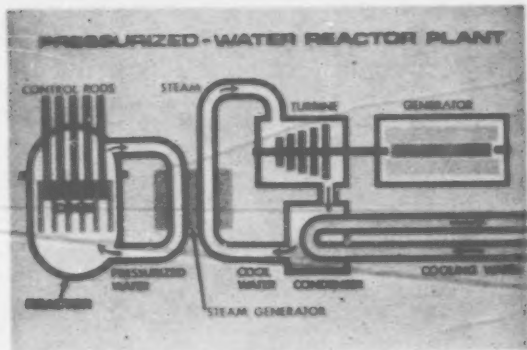
Slide #3



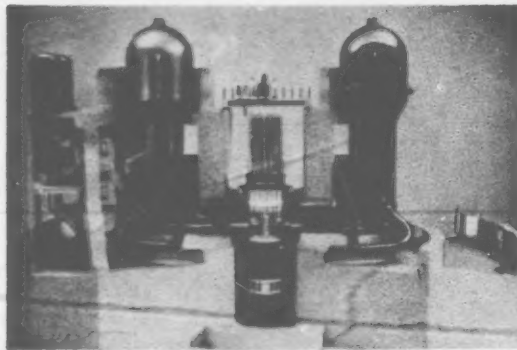
Slide #4.



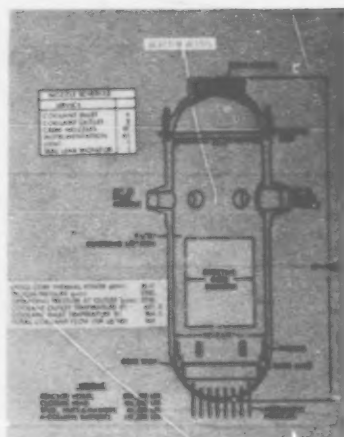
Slide #5



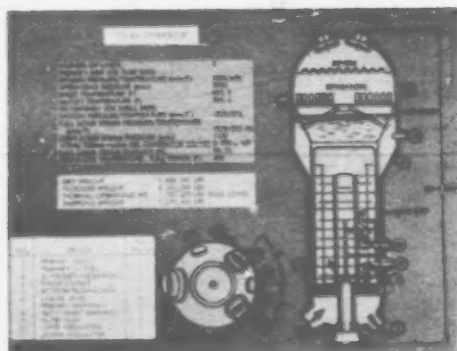
Slide #6



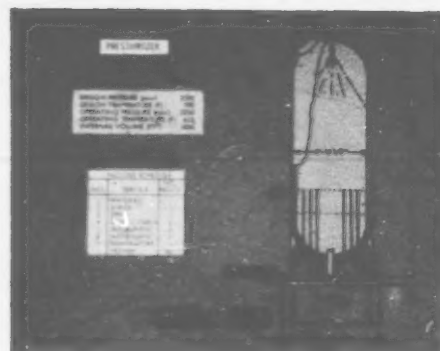
Slide #7



Slide #8



Slide #9



Slide #10

GAS COOLED REACTORS, LIQUID METAL REACTORS AND ALTERNATIVES

By
DR. MERWIN L. BROWN

**Senior Research Analyst
Arizona Public Service Company
P.O. Box 21666
Phoenix, Arizona 85036**

GAS COOLED REACTORS, LIQUID METAL REACTORS AND ALTERNATIVES

I was a little concerned about being scheduled on the morning of June 9, the day after the voting on Proposition 13 in California. I was afraid that I would possibly get up here and talk about a future of nuclear power that had become quite shakey. It looks, however, as if nuclear does have a good future but I think a lot of people don't know about it. There are some nice things coming down the road that look promising.

I want to discuss the future of nuclear power and not dwell too much on the conventional systems of today since those have been discussed earlier. I won't, however, be able to cover everything in 50 minutes. There are a lot of subjects such as enrichment, fuel reprocessing, and waste disposal that are going to be covered by other people. I will, therefore, limit my talk to just the nuclear power plants themselves and what things can be done to improve the situation there. I've listed a few of the goals that are related to nuclear power plants (Figure 1).

We want to reduce capital investment of these plants. In other words, make them cheaper, if we can. This is a relative thing, by the way, because the costs will continue to escalate. But what we want to do is level these costs off as much as possible by proper design of the power plant. We also want to reduce the fuel cost, increase the fuel supply, and increase efficiencies. These items are interrelated. If the thermodynamic efficiency is increased, for example, so is the fuel

supply, and probably at a reduced fuel cost. The thermal pollution that is an aspect of all thermodynamic plants is also reduced with increased efficiency.

Another goal is to reduce water consumption for plants that require water cooling. As you'll see, some plants that I'll talk about for the future do not require water for cooling.

We want to increase the siting availability. In other words, we want to have more sites available to us; so we try to design plants so that they aren't quite as restricted as to where we can build them.

Lastly, we would like to increase the spectrum of applications beyond electrical generation and try to replace dwindling supplies of other fuels with nuclear power where we can.

An examination of available energy sources will indicate why we're very much interested in nuclear energy (Figure 2). Comparisons of gas, oil, coal, etc., reveal the relatively large potential for nuclear energy. Although the fuel potential for modern day, conventional reactor systems is in the same order of magnitude as the fossil fuels; the potential for fission fuels in advanced reactors is tremendous. The energy content of yellow cake, or U_3O_8 , and thorium, another very good potential reactor fuel, is about 10 times the combined content of all fossil fuels. Note for reference that the energy potential of oil, about 3×10^{18} BTU's, is approximately what will be used in the U.S. between now and the year 2000. In conclusion, fossil fuel supplies are limited and yet we rely on them solely. The long term potential resides in the use of uranium and thorium in advanced reactor systems.

There are renewable resources that hold real promise such as solar, hydro, tidal, geothermal, ocean gradients, wind, and fusion [which is

not strictly renewable⁷ (Figure 3). Natural gas and oil is shown here for comparison. By the year 2000, these renewable sources are expected to meet only 11-14% of our total energy supply. This limited usage results not because there's an energy or a fuel supply problem, but because there's a problem in commercializing these technologies quickly. You can only build things just as fast as you can develop the hardware that goes along with it. In other words, we are very inertia conscious and it's difficult to change things rapidly. With respect to this situation, nuclear energy holds great potential.

Practically all the methods available for getting energy out of nuclear fuel are similar to those used in a typical power plant (Figure 4). All typical power plants that use thermodynamic machinery require a thermal energy source at high temperature, if possible. This thermal energy source is used to heat a working fluid, such as water, to a high temperature and pressure. Then the fluid, usually gaseous at this stage, is allowed to expand through a turbine to turn a shaft connected to a generator that produces electricity. Nuclear power plants are not much different (Figure 5). The only big difference is that the energy source now becomes nuclear fuel and the combustion process, for example, is replaced by a fission process, the splitting of a large nuclei.

You've had reactor physics, or fission theory, earlier so I won't belabor the point. I would like to stress a few points that are good for review because we are going to need them when discussing advanced systems. Figure 6 shows an artist's conception of the fission process. A large nucleus, like uranium, is hit by something, e.g., neutron, which induces the splitting. There are other methods, by the way, but use of the neutron is the most common one. The result of the splitting is two

smaller nuclei plus the release of energy as mass was converted into energy.

The fission process also released a few neutrons. At least one of these neutrons must strike another atom of fissile material that fissions, or splits, to sustain the reaction. The other neutrons may do something else; some of them will leak out, while others will be absorbed parasitically (in other words, in a poison material such as reactor structure or control rods). Neutrons lost do no good and, in effect, cost you money.

In some instances, neutrons may be absorbed by a non-fissile material, such as U^{238} , that in turn becomes fissile material such as plutonium. In other words, a "fertile" material becomes a fissile material that can be used in a nuclear reactor. Thus, the neutrons produced during fissioning, beyond the ones needed to keep the chain reaction going, can be used to increase the fuel supply. This process is loosely called "breeding".

There are various kinds of reactors, as shown in Figure 7, that use the same basic fission process but in different manners that require different components. Neutrons born in the fission process are very high in energy, or speed, and in certain reactors it's better to slow them down. These reactors incorporate a moderator that slows the neutron. Whether or not a reactor needs a moderator depends on the design. Some reactors can run on fast neutrons and thus, do not contain a moderator. All power reactors need a coolant for removing the energy that ultimately appears as thermal. Figure 7 shows a matrix of various types of reactors categorized according to moderator, coolant, and fuel used. The moderator is usually a solid or liquid; the coolant, a liquid or gas. Note that in some reactor types the moderator and coolant are one in the

same. Reactors utilizing a moderator are called "thermal"; those having no moderator are called "fast", in reference to the fission neutron speed. Fast reactors are usually breeder reactors and use plutonium as fuel.

The common commercial reactor in the USA is the light water reactor (LWR). The LWR is a thermal reactor fueled by slightly enriched uranium and cooled and moderated by ordinary water. Figure 8 shows an artist concept of the Palo Verde Nuclear generating station to be built west of Phoenix, Arizona. This particular light water reactor is a pressurized water reactor. Note the characteristic secondary containment domes, turbine buildings, peripheral buildings, and cooling towers.

The other LWR, a boiling water reactor (BWR), is shown in Figure 9 in schematic format. It is a very simple reactor much like a conventional fossil plant. Steam is produced in the core and then it expands through a steam turbine-generator. The condenser removes what is called the thermodynamically unavailable energy, or waste heat, after the steam leaves the turbine. The condensate is pumped back to the core.

The pressurized water reactor, PWR, shown in Figure 10, is more complex. The first coolant loop is pressurized like the water in your car radiator so it won't boil. Steam is generated by the pressurized primary loop in a steam generator connected to a secondary water loop containing the turbine-generator. The practical differences between the BWR and PWR are not significant enough to clearly make one concept preferable over the other. Both are very popular in the USA and are becoming popular in other countries.

Figure 11 describes the typical light water reactor which I call the "reliable work horse". It's a very good reactor and as you've probably

heard many times over, is very safe and efficient. Today, it is one of the most economical power sources. A typical power capacity is 1000 megawatts. The capital cost is approximately \$800 per kilowatt although this figure is very site and time dependent. The approximate average busbar energy cost today is about 12 mills a kilowatt hour.

The thermodynamic efficiency of LWR's is about 33 percent. We would like to increase that efficiency if possible. LWR's are pretty much limited to 33% because of temperature and pressure considerations in the core. We, therefore, are considering reactor concepts that allow higher temperatures and consequently, higher efficiencies. LWR's have been experiencing a capacity factor of 60-70 percent and this number has been increasing, some as high as 95%. Increasing the capacity factor, i.e., keep that reactor operating as much as possible, is a major item in keeping the energy cost down.

Enriched uranium is the fuel used by LWR's. Although there is enough uranium in the U.S. for reactors planned or being built without breeders, as you will see, the fuel supply for LWR's is limited. More investment for enrichment facilities is needed. We need reactors, called advanced convertors, that use nuclear fuel more efficiently and we need good breeders.

The PWR has a conversion ratio of 0.55, i.e., for each fissile nucleus consumed, 0.55 fertile nuclei are converted to fissile nuclei. Thus, the PWR can theoretically "convert" enough fertile nuclei to meet almost half of its own fuel needs. The conversion ratio for the BWR is somewhat less. As you will see, advanced convertors can achieve even higher ratios.

The LWR is used mostly for electrical generation and ship propulsion.

With other nuclear reactor concepts, we can expand the range of applications to allow nuclear fuel to meet more of our needs if necessary.

Assuring a long term supply of nuclear fuel is one major goal. It's clear from Figure 12 that there is a great amount of uranium in the U.S. The problem is getting it in a form we can use. The bar on the left represents that uranium considered as reasonably available. We estimate there are about $3\frac{1}{2}$ million tons of yellow cake (U_3O_8) available. We are certain of about 20% of this amount. Comparison with the remaining bars shows how very little of the actual uranium is economically available, up to 4000 million tons in sea water. The problems with using all of this uranium are cost and in some cases, environmental considerations in obtaining these ores. They are difficult to get for a number of reasons. So, for the most part, we are mostly limited to what is available on the far left of the graph. Some day we may get desperate and have to go for the balance of the uranium but with breeders that course of action should not be necessary. Figure 13 gives a detailed breakdown of the $3\frac{1}{2}$ million tons of available yellow cake in the U.S., plus that similarly available in foreign reserves. In the U.S., about 700,000 tons are proven. The rest of the $3\frac{1}{2}$ million tons is more or less a speculation although it is based on very good estimates. The world situation is about the same as the U.S. There is an estimated 4 million tons in the balance of the world.

How we use this fuel supply is important. It may last 40 years or 1000 depending on how we develop reactor technology. The light water reactor cannot use much of the uranium found in nature. Only 0.71% of natural uranium is U-235 which can be directly used in a thermal reactor

(Figure 14). The remaining 99.3% is U-238 which is mostly non-fissionable. Although some of the U-238 is converted by the LWR into fissile material most of it goes unused. The graph in Figure 15 illustrates the reserve value of the 3½ million tons of yellow cake. With a light water reactor industry this reserve would allow commitments until around the year 2000 and will fuel those reactors until about 2040, if no others were built.

Obviously, we have a limited future without the breeder reactor. The breeder reactor generates electricity and creates more fuel than it consumes. Figure 16 puts the breeder in perspective. The conventional LWR can use about 1-2% of the energy available in uranium. Remember, it has only 0.71% of the uranium available as an actual fissile material but all reactors convert some of the fertile material, like U-238, into a usable fuel like plutonium. The breeder reactor does a better job by getting 60% of the available energy out of uranium.

The breeder concept is not magic nor violates any physical laws. Figure 17 illustrates the breeding principle. A fire started with some dry logs can be surrounded by wet logs to catch some of the waste heat. Thus, what were once noncombustible wet logs become additional fuel for the fire. The breeder works on a similar principle. It takes a useless material and conditions it so that you can use it in a reactor as a fuel and it conditions more than it consumes in the process. Figure 17 also shows the makeup of a breeder reactor. The reactor core contains the fissile material such as plutonium (that's what most of them use). A fertile material, like uranium-238, is placed around the core as a blanket to catch escaped neutrons that are used to produce new fuel. That's the breeding concept.

Figure 18 shows the breeding process on a simplified microscopic

scale. A neutron induces fissioning in the fissile material. Energy plus neutrons are produced. Some neutrons hit the fertile material, U-238 in this case, that ends up as another reactor fuel such as plutonium.

The fertile materials that we have to work with are uranium-238 and thorium-232, both about equal in abundance in the U.S. The fuel they produce in the breeder reactor, or any reactor, is plutonium-239 and uranium-233, respectively. These two breeding processes are shown in Figure 19. The plutonium makes a good thermal reactor fuel but an even better fast reactor fuel. U-233 is the best thermal reactor fuel known.

The terms "conversion" and "breeding" ratios have been used above heuristically. Figure 20 defines these terms. The difference between them is one of magnitude. The conversion and breeding ratios are defined as the number of fissile atoms converted from fertile ones divided by the number of fissile atoms consumed. Conversion ratios are less than or equal to one, while breeding ratios are greater than one. Obviously, converter reactors such as the LWR or high temperature gas cooled reactor (HTGR) produce only a fraction of their fuel needs. Breeder reactors, such as the liquid metal fast breeder reactor (LMFBR) or the gas cooled fast breeder reactor (GCFR), produce more fissile material than they consume. The light water reactors have conversion ratios of 0.5 to 0.6. The HTGR, an advanced converter reactor, has conversion ratios of 0.6 to 0.9. The liquid metal fast breeder reactor produces breeding ratios of 1.1 to 1.3 and the gas cooled breeder reactor 1.2 to 1.5. These values will probably have to be revised downward because of recent discoveries but the relationship of magnitudes between

the two breeders will remain. A basic goal, although not exclusive, in reactor design is to achieve as high conversion ratios and breeding ratios as possible.

Another term closely related to the breeding ratio is doubling time, which is how long it takes to double the amount of fuel available. In other words, as illustrated in Figure 21, let's say that in 1975 you start out with 100 atoms of fuel (U-235 or plutonium). Then in 1985, you manage to have a net supply of 200 fissile atoms (U-233 or plutonium) available from the reactor. The doubling time would be 10 years. This term is significant in view of the anticipated energy demand doubling time and the anticipated growth in reactor construction. Ultimately, the doubling time of breeder reactors may be limited on growth.

The LMFBR, liquid metal fast breeder reactor, shown in Figure 22, is so called because it is a fast reactor, is cooled by a liquid metal, and breeds fissile material while producing a net electrical energy output. For reasons beyond the scope here most breeder concepts are fast reactors. Liquid metal, usually sodium, is chosen as the coolant because it is a good one but also because it does not significantly moderate neutrons. Water, also a good coolant, moderates. The LMFBR has two sodium and one water coolant loops. The primary sodium loop cools the reactor core but since it becomes radioactive upon bombardment by neutrons, it cannot be allowed near the steam generation loop because of the possibility of a water/sodium reaction that might release radioactive sodium. Thus, a non-radioactive sodium loop, called the intermediate loop, is used to transfer energy from the primary loop to the water loop where steam is generated for the turbine-generator.

The history of the LMFBR in the U.S. started long ago as shown in

Figure 23. Experimental Breeder One was built in 1951 and also happened to be the first reactor in the United States to generate electrical power. As evident in Figure 23, there has been a steady progression of LMFBR's. Some generated power while others were used strictly for experimentation but none were commercial. Today, we're building the FFTF, fast flux test facility, which generates no electrical energy but will be used primarily to test components for our first demonstration breeder reactor, the Clinch River breeder reactor (CRBR). The CRBR is planned to start construction soon near Oak Ridge, Tennessee, and when completed in the mid-1980's, will appear as shown in Figure 24. The Clinch River breeder reactor will generate between 300 and 400 megawatts electrical and will essentially be the first breeder designed as a utility type reactor.

Foreign countries are also working on breeder reactors; Russia, United Kingdom, France, Japan, and West Germany. It turns out that most of them are ahead of the United States, as shown in Figure 25. France has had a demonstration LMFBR similar to the U.S. Clinch River for about a year. In general, the United Kingdom, Russia and France are ahead of the U.S. We argue that we are building a better reactor by taking more time.

A study was recently performed to look at the benefit of the breeder i.e., LMFBR. The method used compared the energy cost to the nation with and without the breeder. In this case, the government development costs were not initially included but were considered in the conclusion. The key issues involved were breeder costs and uranium availability. If there is plenty uranium the breeder doesn't have near the cost advantage as if there's not enough uranium. Of course, if breeders are excessively costly, their fuel savings may be irrelevant. Some of the base case assumptions for this study are listed in Figure 26. They are quite conservative.

One significant benefit of the breeder is a reduction in mining, illustrated in Figure 27. Without the breeder, the mining capacity keeps right on climbing which means removing a great deal of dirt in the future. Another significant benefit is an increased fuel supply. The uranium reserves with a breeder increase to approximately 1000 years from a 40 or 50 year supply without breeders.

The cost/benefit study concluded that the discounted benefit, that's the present worth, of the breeder reactor being commercialized in 1989 is 76 billion dollars to the nation through the year 2000. Since the cost of developing that reactor will be about 7 billion dollars, the benefit is about 10 times the cost. This ratio is illustrated in Figure 28. By the way, that 76 billion translates to 2.4 trillion dollars in actual dollars.

If we were to assume the LMFBR cost twice what a light water reactor cost, the discounted savings to the U.S. would still be 31 billion dollars. If we assume that uranium will be about twice as plentiful as estimated, we still save about 44 billion dollars discounted. Delaying the introduction of the commercial LMFBR 10 years, until 1999, reduces the net benefits to 43 billion dollars versus 76 billion and if we delay it 20 years, it drops to 19 billion dollars. This analysis is summarized in Figure 29.

Before further discussion of breeder reactor concepts, we need to talk briefly about gas-cooled reactors. The gas-cooled reactors differ from the liquid-cooled discussed above in, of course, the physical state of the coolant fluid and the containment. The high temperature gas-cooled reactor, HTGR, shown in Figure 30, uses helium as a core coolant and a prestressed concrete reactor vessel instead of the conventional steel

vessel. The use of helium allows for higher core temperatures and a fuel design that can take the higher temperatures. Thus, the hot helium "blown" from the core can be used to generate steam at an efficiency comparable to that of the advanced fossil-fired power plants. This situation saves fuel and reduces cooling water needs. An artist concept of an advanced HTGR is shown in Figure 31. Note the similarity to LWR power plants. The major difference in appearance is the core. Also note the relative size of the large turbine building characteristic of steam generating plants. As you'll see later on, the HTGR has the capacity to reduce capital costs by substituting a compact gas turbine for the steam turbine.

The prestressed concrete reactor vessel is illustrated in Figure 32. Because of the higher pressures coupled with the large volume required for gas coolant such a vessel is required. The vessel is prestressed by vertical and circumferential steel tendons that make for a strong, tight containment. It contains the core, the steam generator and the helium circulators. An auxiliary emergency cooling system is also included. The typical metal-clad fuel rods cannot be used in this high temperature environment. Thus, the fuel configuration shown in Figure 33 was developed. The fuel, U-235 or U-233, is incorporated in small B-B size particles coated with graphite and silicon carbide. One type of particle contains just fuel while another contains thorium-232 used to "breed" U-233. The silicon carbide coating on the fuel particles essentially make them into the primary containment vessel for fission products. Indeed, the Fort St. Vrain HTGR was licensed on that basis. These particles are mixed into a graphite matrix that is formed into rods about the size of a pencil in diameter. The rods are then put in a hexagonal graphite block. Since

the HTGR is primarily designed for the thermal fuels U-235 and U-233, graphite serves as the moderator. The real advantage of graphite, if designed properly, is the high temperatures it can take--way above what the ordinary metal clad light water reactor fuel can take. The large thermal capacity of the graphite and the single-phase gas coolant make the HTGR an extremely safe, easy to manage reactor.

The gas cooled breeder reactor (GCFR) is an off-shoot of the HTGR. Except for the fuel, the two concepts look very similar (Figure 34, 35 and 36) and the metal-clad fuel in the GCFR is similar to that in the LMFBR. Graphite cannot be used because of its moderating properties. Thus, the GCFR is temperature-limited to a similar extent as is the LMFBR. The advantage of the GCFR is that it can be developed using the combined technologies of the HTGR and the LMFBR fuel. The helium allows higher breeding ratios than does sodium and it does not have the safety problem of a phase change. Although not as thoroughly developed as the LMFBR, the GCFR offers the promise of a better breeder. Their advantages and disadvantages are compared in Figure 37.

There are a couple of other breeder concepts not as well developed as the GCFR and LMFBR. Figure 38 shows the molten salt breeder reactor. The fuel is in a molten-salt form that allows a chemical processing plant to continuously process the fuel for a resultant increase in the breeding ratio. This has the potential for being the greatest breeder ever built, but it also is one of the toughest ones to build at the moment because of the corrosion problems of the molten salt.

The light water breeder reactor is shown in Figure 39. It's a pressurized water reactor with a change in the fuel composition. Thorium is included so to breed U-233. The LWBR is a very poor breeder and some

people don't even list it as a breeder. They list it as an advanced converter. It's being built by the Navy as an experiment right now. The advantage is that a lot of the modern day pressurized water reactors may be converted to high converter or a low breeder reactors.

As mentioned above, thorium is a potential nuclear fuel. Figure 40 relates the energy potentials of uranium and thorium in a breeder/converter economy. These two energy sources are nearly equivalent and large. The uranium yields mostly plutonium, primarily a fast reactor fuel; thorium yields U-233 an excellent thermal reactor fuel. Figure 41 illustrates the potential relationship between the uranium and thorium fuel cycles. Before 2000 A.D., the uranium fuel cycle enriches uranium for use in LWRs and HTGRs. It is not a very efficient fuel cycle and the enrichment plant requirement is a bottle neck. After the year 2000, hopefully, we will have a breeder/converter fuel cycle. The basic fuels, uranium and thorium, will be placed in breeders to produce plutonium for breeder fuel and U-233 for converter fuel. The enrichment plant is not needed. Some may wonder why not use breeders exclusively. The reason for a breeder/converter mix is the inherent versatility of the HTGR advanced converter. Without the HTGR, the exclusive breeder economy might then make the better arrangement.

Figure 42 shows the dramatic reduction in mining allowed by the breeder/converter symbiosis. The width of the flow lines is proportional to the mass flow. It is evident that the makeup material flow is very small. This situation would result in significant environmental and economic benefits. The number of advanced converters, such as HTGRs, that can be fueled by one advanced breeder, such as GCFR, is a function of the breeding and conversion ratios. The higher these ratios are the

more HTGRs can be supported. From the graph in Figure 43, one can conclude that one GCFR might support two to three HTGRs while the LMFBR could support only one or two HTGRs, depending on the conversion ratio of the HTGRs. Figure 44 shows the relationships between the plant mix and the annual energy growth rate as a function of breeding and conversion ratios. It is evident that for a growth rate beyond a few percent that only advanced breeders and converters will suffice. This situation illustrates the need for the development of GCFR or Molten Salt Breeders and the HTGR and LWBR.

A study was done that relates the significance of the symbiotic fuel cycle to the U.S. uranium reserves. Figure 45 summarizes the scenarios studied and Figure 46 summarizes the results. The first three base cases do not level-off in uranium demand before exceeding the estimated uranium reserves. Only the case that makes intensive use of thorium/U-233 eases the demand on uranium enough to allow any hope of avoiding imports of foreign uranium. It should be noted that any case where the breeder is used considerably mitigates the problem even if it does not solve it.

The chart in Figure 47 shows the importance of breeders and the symbiotic breeder-thorium converter system in another way. It shows how many 1000 MWe reactors can be sustained on 3 million tons of yellow cake for various fuel cycle economics. The LWR fuel cycle without plutonium recycle could not meet the present U.S. generation requirement if nuclear were the only means. The use of plutonium recycle and advanced converters (HTGR) increases the potential of this uranium reserve by 2 to 5 times. The breeders and the symbiotic system increase the potential by 100 to 200 times which should be enough to meet our energy needs for 1000 to 2000 years.

Another goal is to reduce the thermal pollution aspects of nuclear power plants. Figure 48 illustrates that cooling water consumption is reduced by improving the plant thermodynamic cycle efficiency. LWRs are operating in the 33% range. Our coal plants are operating in the 40% range as will the HTGR and the breeder reactors when they get going. There is one reactor concept that can continue to raise its efficiency because it can continue to raise its temperature and that's the HTGR. But the steam cycle HTGR is limited by the steam cycle component limitations. The same can be said for fossil plants. By replacing the steam cycle with a direct helium cycle gas turbine the HTGR is free to perform as it should.

A schematic of the Gas Turbine HTGR is shown in Figure 49. In simple terms, the steam generator is replaced by a gas turbine. Cooled helium is compressed before being heated in the reactor core. It then is expanded through a closed-cycle gas turbine. Before being cooled, the exhaust helium is run through a recuperator to increase efficiencies. Figures 50 and 51 show an artist concept of the GT-HTGR. Note that the gas turbine placed in the concrete reactor vessel replaces the need for a large, expensive steam turbine and building.

If desired, the GR-HTGR can be dry cooled because of the relatively high rejection temperatures of 200-300°F. Steam cycles cannot be economically dry-cooled because of low top and rejection temperatures. Even at relative low maximum temperatures of 1500°F, the cycle efficiency for a dry-cooled GT-HTGR is above 37%. This efficiency could be increased by raising the maximum temperature to probably around 2000°F. The cooling advantage of the GT-HTGR is illustrated in Figure 52. Note the much smaller structures of the GT-HTGR compared to the steam HTGR and LWR.

The large cooling towers required for dry cooling the steam cycle plants are economically unacceptable. However, if there is some cooling water available, the high temperature waste heat of the GT-HTGR can be utilized. Instead of throwing the energy away in a dry cooling tower that doesn't require water another thermodynamic cycle is put on the bottom to convert some of this waste to electricity. Figure 53 shows a GT-HTGR with an ammonia bottom cycle attached. This combination can achieve efficiencies of at least 45-46% and by raising the reactor temperature (which again, is very feasible), we can go up over 50% and break that magic number. But you sacrifice the dry cooling capability. This situation, though, is not too bad since the amount of cooling water is much less now than it would be for a conventional plant of comparable size.

Another goal is to find other applications. The high temperature gas cooled reactor, because of its high temperature, has a lot of other applications and a few of them are listed in Figure 54. All kinds of chemical processes, coal gasification, oil recovery, shale recovery (of oil from shale), hydrogen production, steel making, desalting, and other things can be done. In other words, your imagination is free to roam here. This situation occurs because the high temperature gas cooled reactor can raise that temperature up to where you can use it. The light water reactors and the breeder reactors are stuck for the time being with lower temperatures.

Thus, in conclusion, the breeder reactor is a major necessary element in our future energy supply and the advanced converter, HTGR, offers many economic and environmental advantages including versatility.

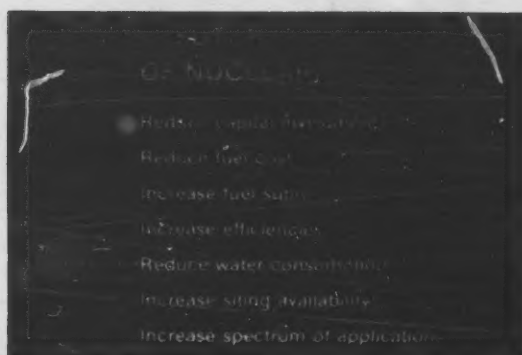


Figure 1



Figure 2



Figure 3



Figure 4



Figure 5



Figure 6



Figure 7



Figure 8



Figure 9

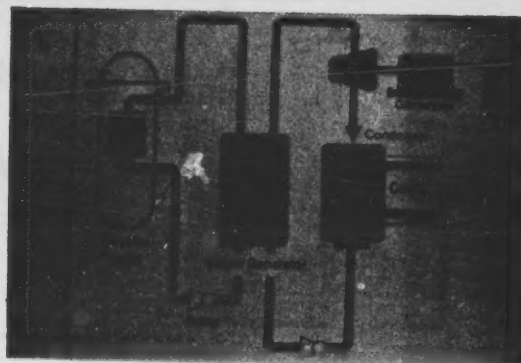


Figure 10

1000 MW WATER REACTOR	
RELIABLE WORKING	
Power capacity	1000 MW
Thermal capacity	1000 S.K.W. 12,000 K.W.
Efficiency	33%
Operating cycle	70-75%
Operating time	24 hours
Operating rate	0.35
Operating cost	Electrical generation
	Ship propulsion

Figure 11

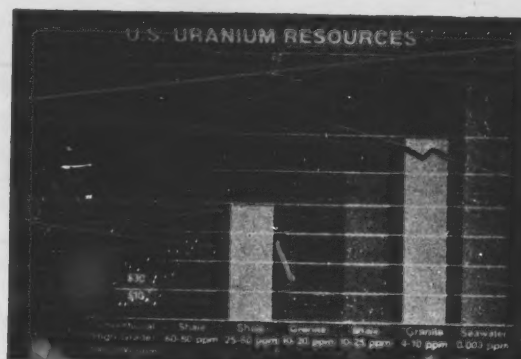


Figure 12

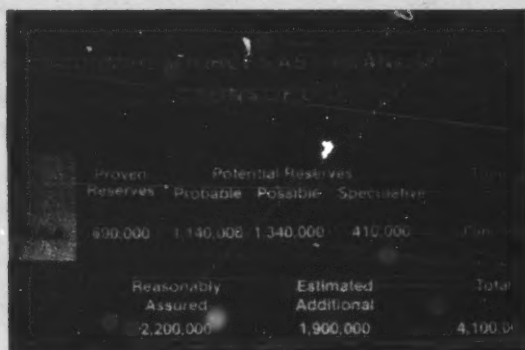


Figure 13



Figure 14

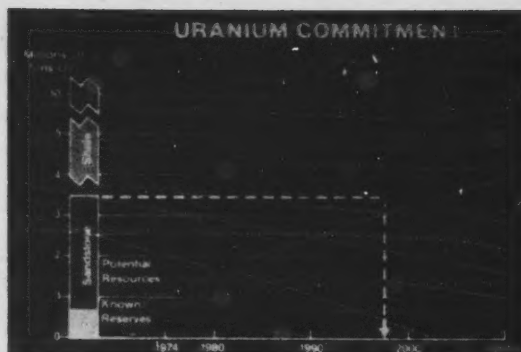


Figure 15

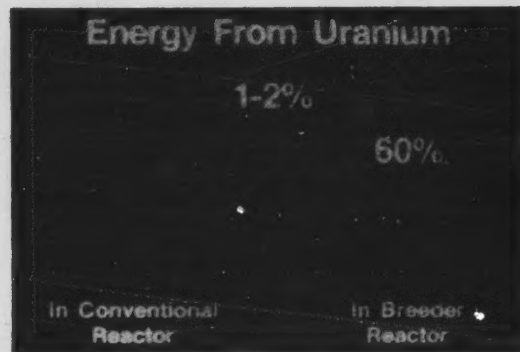


Figure 16



Figure 17



Figure 18



Figure 19



Figure 20



Figure 21



Figure 22



Figure 23



Figure 24



Figure 25



Figure 26



Figure
27



Figure 28



Figure 29

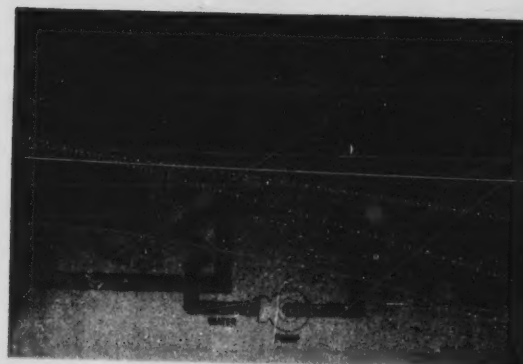


Figure 30



Figure 31



Figure 32

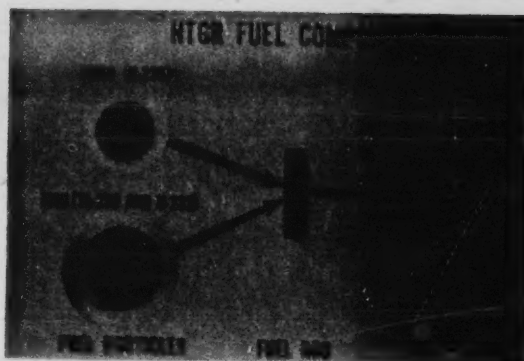


Figure 33



Figure 34



Figure
35



Figure 36



Figure 37



Figure 38



Figure 39



Figure 40



Figure
41



Figure 42



Figure 43



Figure 44

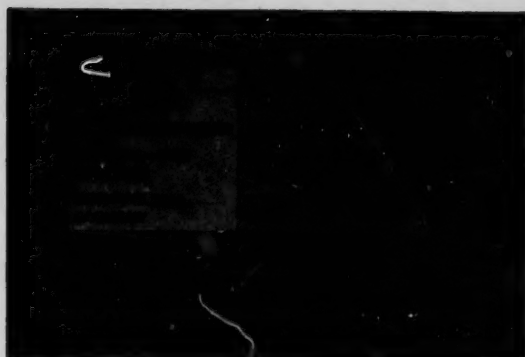


Figure 45



Figure 46



Figure 47

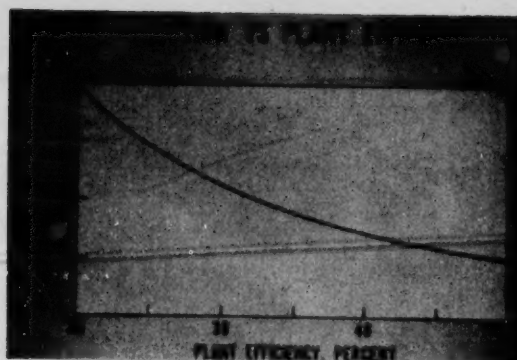


Figure 48

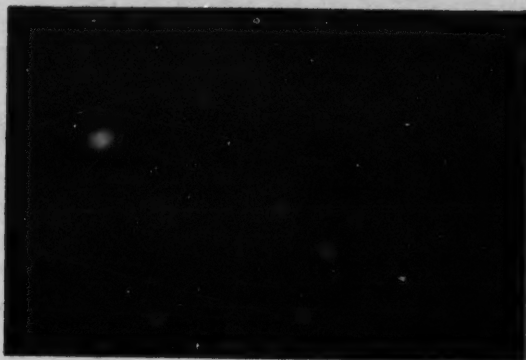


Figure 49



Figure 50



Figure 51

Figure
52

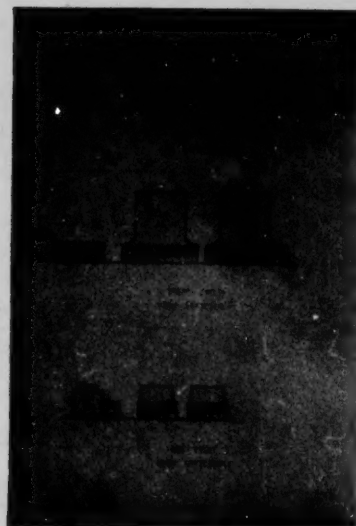


Figure 53



Figure 54

RADIOACTIVE WASTES: DISPOSAL ALTERNATIVES

By
W. P. BISHOP

Chief, Waste Management Branch
Division of Fuel Cycle and Material Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20545

RADIOACTIVE WASTES: DISPOSAL ALTERNATIVES

INTRODUCTION

As you will hear elsewhere in this symposium, one of the major hopes for the supplying of continually increasing amounts of energy to this country and the world is to tap the tremendous energy of the atomic nucleus. In the early days of the nuclear age, we all heard that nuclear electric energy would be so inexpensive that we would need no meters at the home or industrial user. While this has not been the case, nuclear energy is certainly competitive economically. But nuclear energy like all other intensive energy sources has its costs. One of these is the radioactive waste materials which are the inevitable by-product of the production of that energy.

For every atom of uranium or plutonium which breaks apart to release a bit of energy, two fission products--elements of lesser atomic number--are formed. Also, not every atom of uranium which absorbs a neutron in the reactor undergoes fission. Some merely become an element of higher atomic number--the transuranic elements. Almost all of these fission products and transuranic elements are themselves radioactive. Also, almost all of them have a detrimental effect on the operation of the reactor, and thus must be removed periodically from the reactor fuel. This separation and almost every other process in the nuclear fuel cycle produces some radioactively contaminated rubbish--the nuclear wastes which are the subject of my discussion.

What then are these wastes? Where do they come from? What are our alternatives for their safe management and disposal? Who is (or must be) responsible for their disposition? And how do we as a nation decide on the best strategy? These are the five questions I would like to address.

WHAT ARE NUCLEAR WASTES?

The two key concepts are that these materials are radioactive and they are wastes. Thus, we adopt a working definition which is:

Nuclear wastes are those radioactive materials which are of sufficient potential radiological hazard that they require special care and which are of no present economic value to the industry.

The materials are by their very nature radioactive; someone decides that they represent a hazard (and thus require special care); and the industry decides that they are wastes.

WHERE DO THE NUCLEAR WASTES COME FROM?

There is an old adage in the garbage industry that whenever you handle the stuff you get your hands dirty. The same is true in the handling of radioactive materials. Whenever such materials are handled (manufactured, treated, stored, used, etc.) some sort of contaminated debris ensues. Figure 1 shows schematically the nuclear power production--the so-called nuclear fuel cycle (a cycle because some of the material can be recycled to produce further energy). Each step of the cycle produces some amount (large or small) of radioactive wastes. Table I is a summary of projections for some of the different types of such waste integrated across the fuel cycle and across time till the year 2000.

I must note in passing that the majority of the trash presently in need of disposal does not come from nuclear power facilities. The largest volume (though generally only very slightly radioactive) comes from other users of radioactive materials such as industrial processors and medical users. Herein, however, I shall limit myself to a discussion of the wastes from the production of nuclear energy.

WHAT ARE THE CHARACTERISTICS OF NUCLEAR WASTES?

Again referring to Table I, it is possible to describe the parameters on which one may sensibly divide the several kinds of wastes for the sake of discussion and for the sake of developing means for the disposition of these wastes. These parameters include:

- the specific activity (i.e., the amount of radiation emanating from a specific volume or mass of the material),
- the toxicity of the material (which is related to the specific activity and a set of other factors mainly regarding biological processes in the human body and in food plants and animals),
- the lifetimes of the radioactive elements in the wastes (all radioactive elements decay eventually),
- volumes (the major engineering consideration),
- source of the waste, and
- possible disposition of the waste.

The hazard posed by radioactive wastes depends a great deal on how we handle them. At least one analysis of a system for their management shows an impact so small as to be almost negligible. On the other end of the scale, it is clear that complete mismanagement of the wastes (i.e., their release to the environment) could cause a worldwide radiation hazard of severe proportions by the middle of the next century. There will simply not be enough water on the planet to dilute the

materials to safe levels at that time. The lesson is clear; the system for the management of the wastes must be good. It probably need not be perfect (we can tolerate some released radioactivity--though there is disagreement as to how much), but it need be good. We must not intentionally release the material in great quantity.

Figure 2 shows the lifetimes of one of the wastes (high-level waste). From the graph, I make two points: first, the major part of the radioactivity in the high-level wastes (the fission products) decays in a few hundred years; and secondly, the remaining radioactivity is not very intense, but still warrants isolation from the environment. This longer lived material is mainly the transuranic elements and their daughter products. Radioactive elements often decay to other radioactive elements called "daughters" or "daughter products". I am not at all sure why they are not "sons". They will present some hazard (though small) for hundreds of thousands of years (some say longer).

Of course, we must not neglect discussion of all of the other wastes shown in Table I. All of these must be managed and all must somehow be disposed of.

WHAT ARE OUR ALTERNATIVES FOR DISPOSAL?

It is tempting in addressing this question to simply list the alternatives and give their pros and cons, letting the implication be that all are equally desirable. But the acceptability of the techniques depends on a number of factors which must be weighed and balanced. These include: 1) the degree of isolation provided, 2) the rapidity with which they may be implemented, 3) the costs, and 4) our capability to predict far into the future.

I shall go through the list of alternatives for the worst of the wastes (the high-level and transuranium contaminated wastes) without applying judgments such as those above, and remark briefly at the end regarding the desirability of the alternatives.

Figure 3 shows the set of options which are usually discussed for the final disposition of high-level wastes. Most of them apply as well to all classes of waste with a few special exceptions.

Today there are a few possible uses seen for the radioactive wastes. These all depend either on the very high radiation output of the wastes or on some special valuable component of the waste which must be separated from the rest of the material. Thus, for the majority of the wastes any utility will also decay in time and thus, such use is an interim measure.

One would really prefer to be completely rid of the dangerous isotopes in the wastes and not need to rely on isolating them somehow from the environment. Two methods have been proposed for accomplishing this riddance. The most glamorous is what is called transmutation--the destruction of the isotopes by putting them back into a reactor (or another neutron source) to produce more benign species. This is theoretically possible for the most of the transuranic isotopes, and for some of the fission products. The second method is the rocketing of the wastes into space. This might be possible (even in the light of serious safety precautions required) for a part of the wastes, but shielding requirements make it nearly impossible to so ship all the highly radioactive fission products.

Both of the above technologies depend on the ability to separate the wastes into two parts--that which can be transmuted or shipped

into space and that which cannot. The latter portion must be disposed of on the planet earth. In fact, the technology for the separation of the wastes (called partitioning) has never been used for that purpose and is not yet ready for application.

Thus, today (and no matter what the future holds) some or all of the waste must somehow remain on the earth in a way that it is isolated from our environment at least until it decays to some innocuous level. For the long-lived materials our judgment today is that this requirement means burial deep in some part or parts of the earth's crust.

In searching the face of the globe for suitable places, we have tended to use four criteria in selecting attractive areas. These are:

- geological stability (or predictability),
- lack of resource potential,
- special properties of the rock formation (e.g., plasticity, dryness, etc.), and
- unlikelyhood of future high population density in the vicinity.

Perhaps the most difficult requirements are the second and fourth which depend on prediction of future human activities.

We do much better at meeting the other criteria, or convincing ourselves that we can meet them. For stability, we look to areas where geological activity is slow and cataclysmic events occur infrequently. This means in practice staying away from edges of tectonic plates, major watersheds, glacial areas and volcanic activity.

Some of the rock types which show promise are salt, clays, shales, and hard crystalline rocks (e.g., granite). Figures 4-6 show regions in the United States with these types of rocks.

One other area which deserves special mention because it apparently meets the two more difficult criteria (population and resources) is the geological formations under the sea. In some areas of the oceans (see Figure 7) there is almost no possible resource potential, there is certainly no likelihood of population density, and stability is the very essence of the environment and has been so for 150 million years.

For wastes of lesser hazard or short lives, we need less drastic measures. Today, we bury many of these low-level wastes in what amount to landfill operations (though a bit more carefully done than most landfill operations). While this sort of disposal is now under review at both NRC and ERDA, there is no serious reason today to believe that it is not suitable for some radioactive wastes. We all seem to agree that it is not suitable for high-level or very long-lived wastes.

Finally, there is the vast quantity of water in the oceans. This fluid has been the final resting place and diluent for much of our trash in the past. And while the U.S. has ceased dumping any radioactive material into the ocean, other nations continue such dumping and with special permits, it is still legal in this country. In fact, there are some short-lived materials which are difficult (if not impossible) to solidify for which the ocean waters may still provide the best protection.

There is one sort of waste which deserves special mention because it is relatively incapable of removal to a repository or burial ground. That is the slightly contaminated facility which has outlived its utility and has been taken out of service (decommissioned). The range of possibilities for protection from the small amounts of radioactivity in such buildings extends from administrative controls such as fences

and guards, to entombment in place, to actual removal. The U.S. has not established policy regarding this sort of radioactive waste.

WHO IS RESPONSIBLE?

For many years an assumption was made that the industry would handle the problem of nuclear wastes along with all of the other technologies in nuclear power. But the management of nuclear wastes is at best only marginally profitable and is thus, a burden on organizations charged with providing profits to their stockholders. And wastes were similarly a burden to the early AEC managers who had the responsibility to develop and prove technology for the tapping of the energy of the atomic nucleus.

It is now clear that the Federal government must take responsibility for the management of the wastes--not bear the costs nor necessarily operate the facilities, but take the responsibility for action. There are two aspects of having a successful system for the management of nuclear wastes. One is having the technology available. I have briefly addressed the technology and it seems that there are alternatives for disposal of these wastes. The other aspect is the implementation of the technology, the establishment of an operating system. Waste management technology is not self-implementing.

Further, it is clear that the need for isolation from our environment continues into the future for periods longer than most of our social institutions will survive. Thus, we cannot put off the implementation of a waste disposal system to unknown generations or unknown technologies. Of course, future generations are likely to be smarter than we are. But the prudent action (and the equitable one) is to

bear the burden of disposing of the wastes today as we reap the benefits of nuclear energy.

So, we today must be responsible for our own trash and the Federal government has assumed the responsibility for action. This resolve was made clear by the Administration and all of the involved agencies in recent testimony to the Joint Committee on Atomic Energy.

HOW DO WE DECIDE ON THE BEST STRATEGY?

In principle, the answer is easy. We set some goals, and we select the technology and management system which best meets those goals. The statement of goals for waste management (and particularly waste disposal) has not been explicit. For most other wastes throughout history the goal has been something like "out of sight (or out of site), out of mind." We must do a little better for nuclear wastes.

Let me suggest a few goals we might use. I shall not try to assess which of the disposal alternatives best meets the goals for this process of selection is now going on in the Federal agencies.

Some of these goals are to provide:

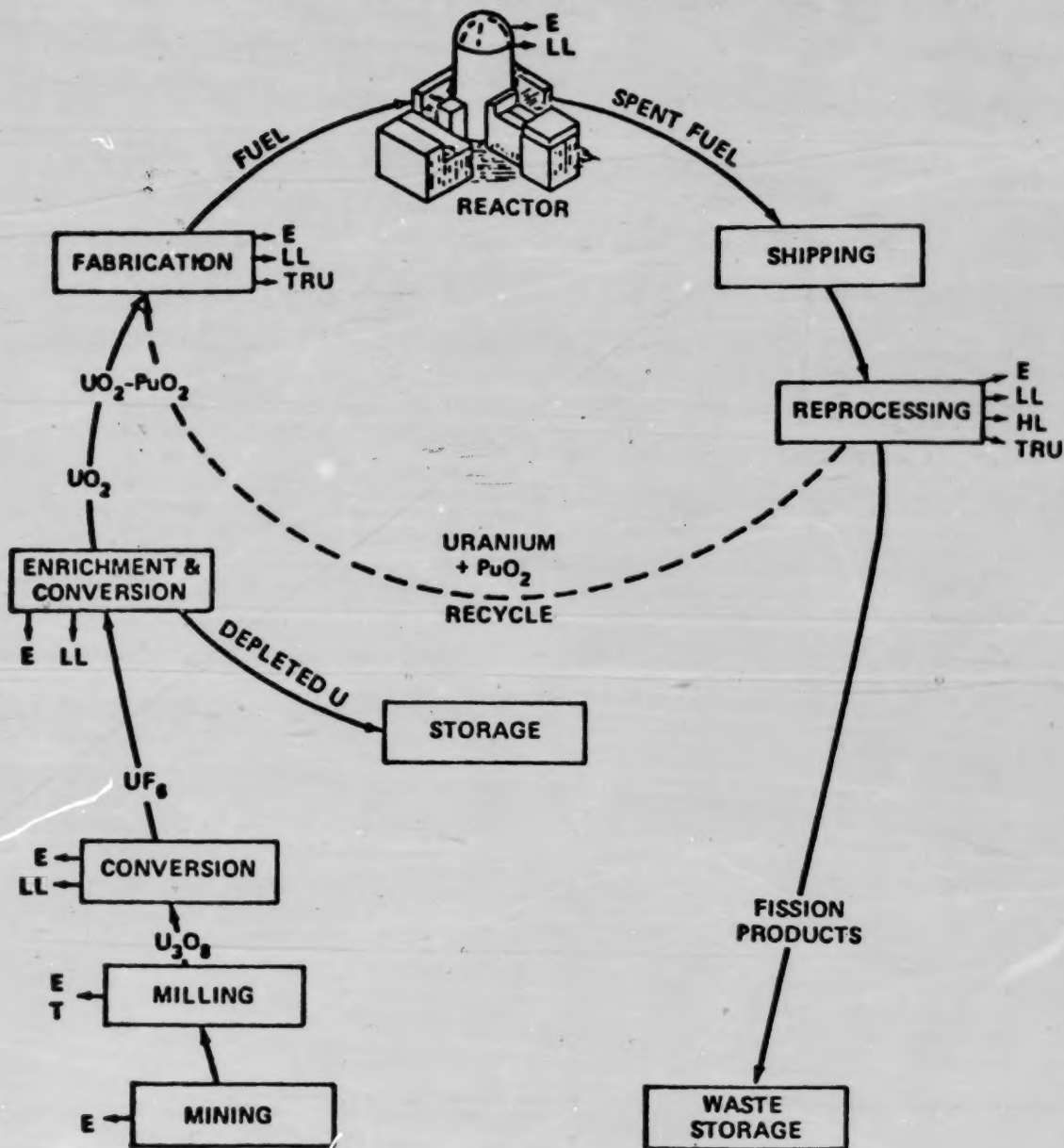
- protection against radiological risk or hazard,
- protection of important institutional values (e.g., civil liberties, democratic institutions, etc.)
- no reliance on social institutions in the long-term,
- assumption of responsibility for action today (bearing the costs while we accept the benefits),
- minimal interference with other resources or activities of mankind, and
- assurance to all (through a process of decision-making involving all who care) that the actions are appropriate.

You will see the three elements of the goals--technology, implementation of that technology, and acceptance of both of those--all aimed at protecting what we find valuable.

SUMMARY

What then are our alternatives? First, waiting around is not an alternative--at least not one we can or should consider. What we can and should consider are the technologies for geological disposal, space disposal, transmutation, and sea (or seabed) disposal. It is interesting that these might fall into some older classes of things--earth, air, fire and water. The only remaining question is which is better. Most of us are leaning toward the earth.

COMMERCIAL NUCLEAR FUEL CYCLE AND TYPES OF WASTE GENERATED



LEGEND

- E** - RELEASABLE IN EFFLUENTS
- HL** - "HIGH LEVEL" RAD WASTE
- LL** - "LOW LEVEL" RAD WASTE
- T** - MILL TAILINGS
- TRU** - TRANSURANIUM - CONTAMINATED RAD WASTE

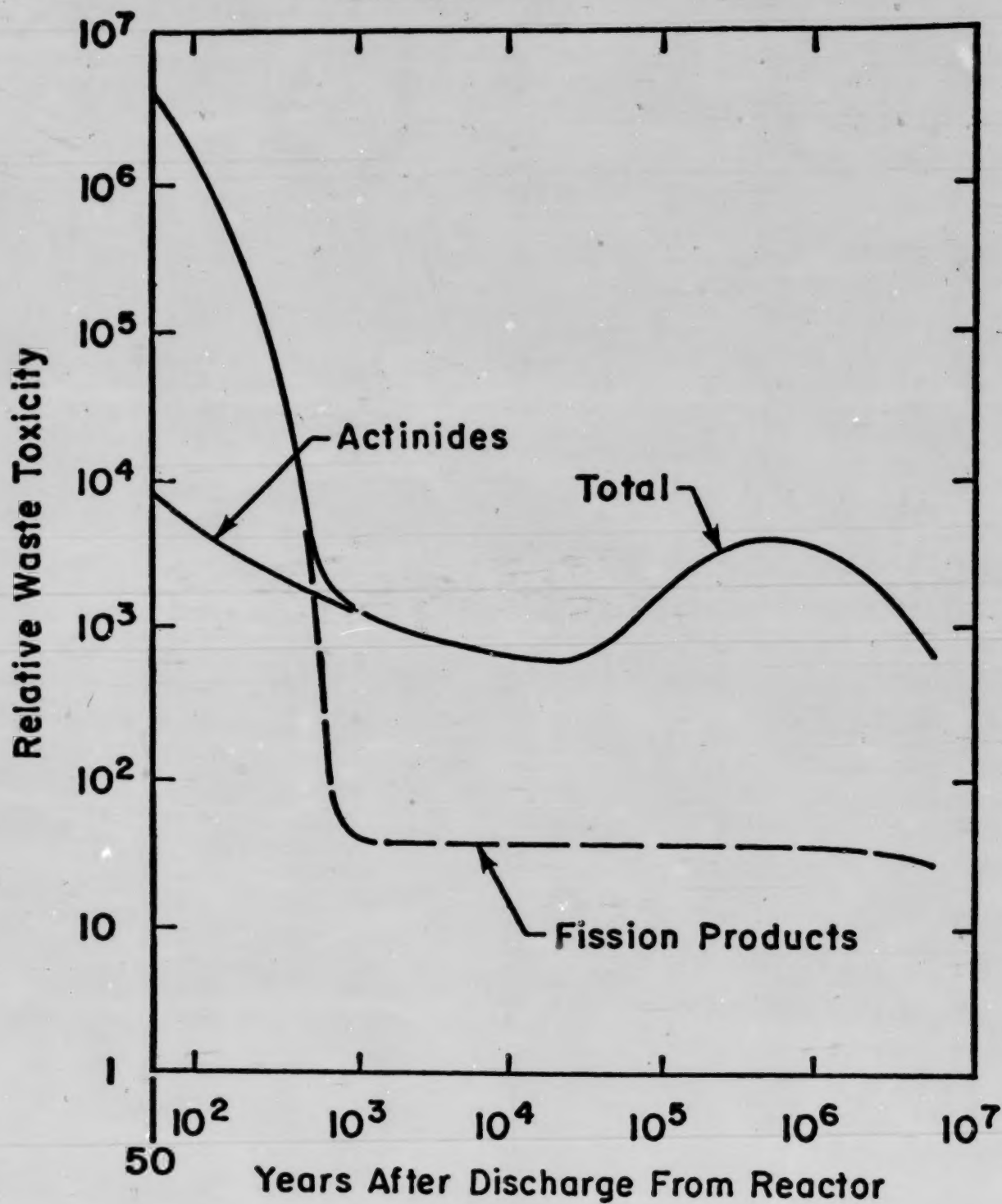
FIGURE 1

FUEL CYCLE WASTES PROJECTED FOR THE YEAR 2000*

	<u>ANNUAL GENERATION</u>		<u>TOTAL ACCUMULATED INVENTORY</u>	
	<u>VOLUME (10³ FT³)</u>	<u>ACTIVITY (MCi)</u>	<u>VOLUME (10³ FT³)</u>	<u>ACTIVITY (MCi)</u>
HLW (solid)	50	60,000	471	75,000
CLAD	54.0	250	450	900
TRU	700	5.5	5,400	24.2
LLW	54,000	1.0	330,000	4.0
GASES	2,200	23.0	21,000	1,500
TAILS	2,400,000	0.8	31,000,000	9.9

* Assumes Pu Recycle

FIGURE 2



LIFETIME OF HIGH-LEVEL WASTE

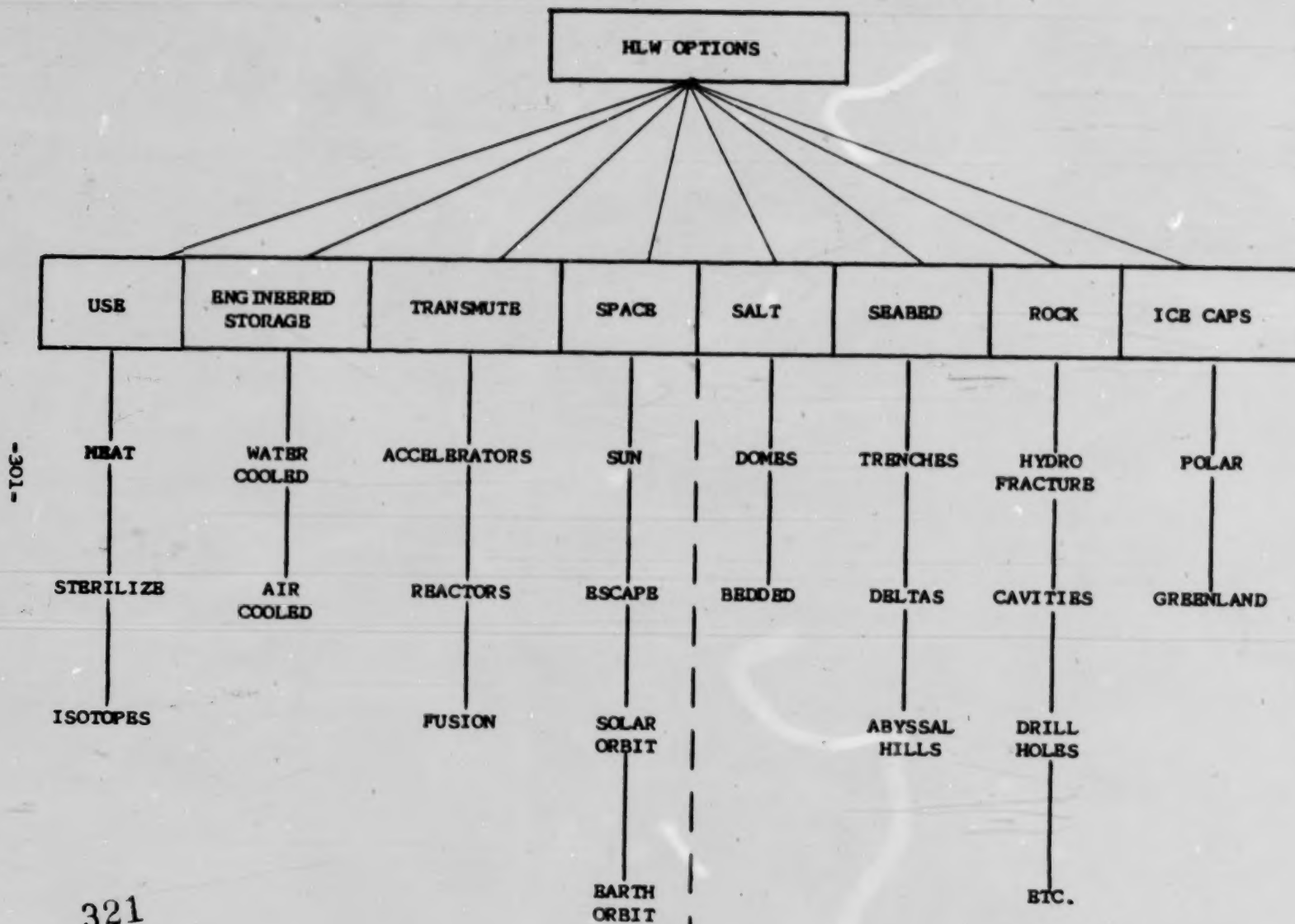
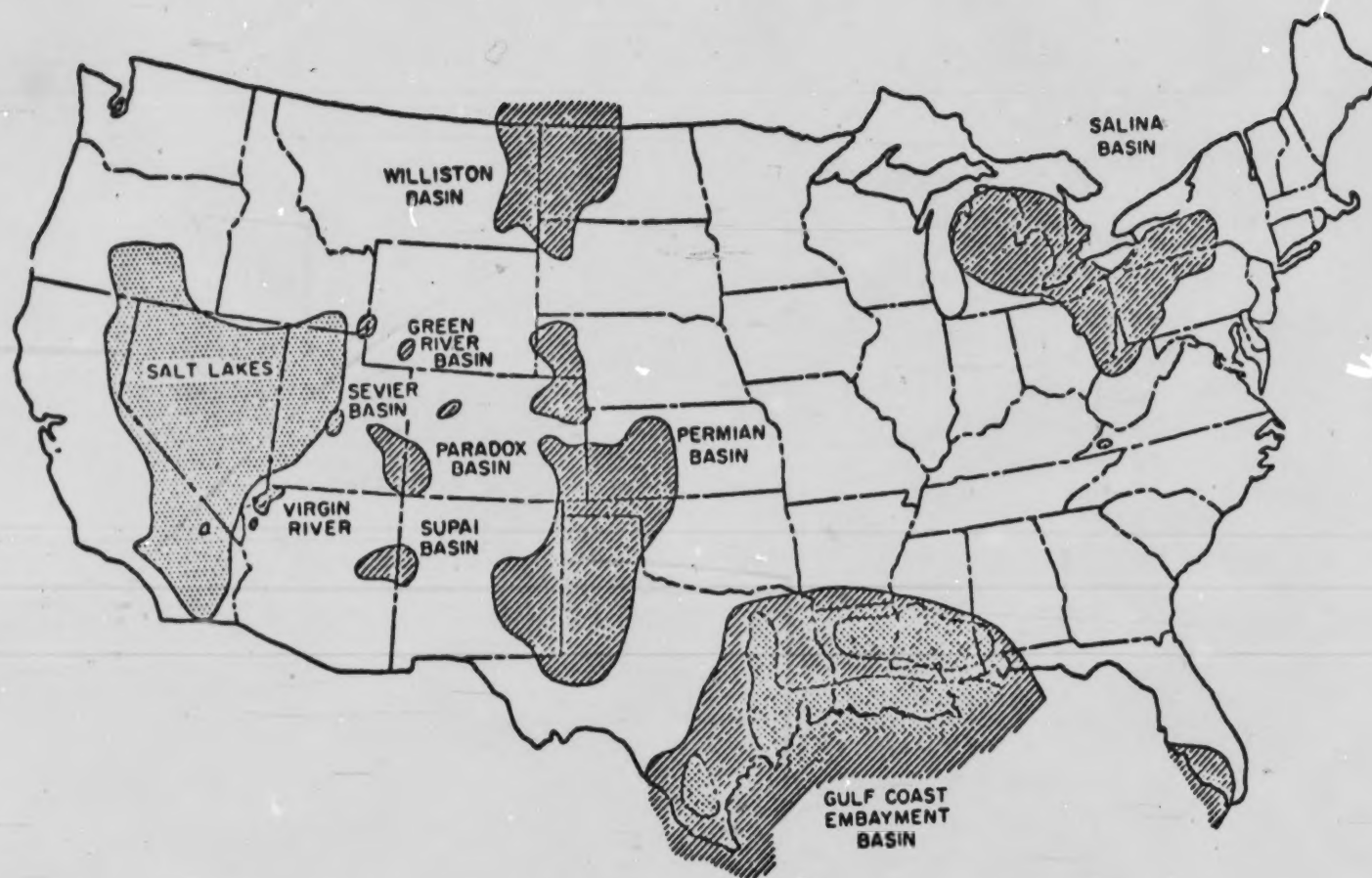


FIGURE 3 - OPTIONS FOR HIGH-LEVEL WASTES





CRYSTALLINE FORMATIONS IN UNITED STATES

325

FIGURE 5

326



-304-

327

ARGILLACEOUS FORMATIONS IN UNITED STATES

FIGURE 6

328

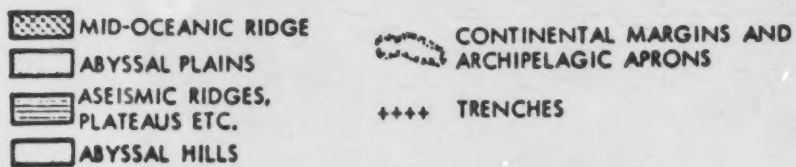
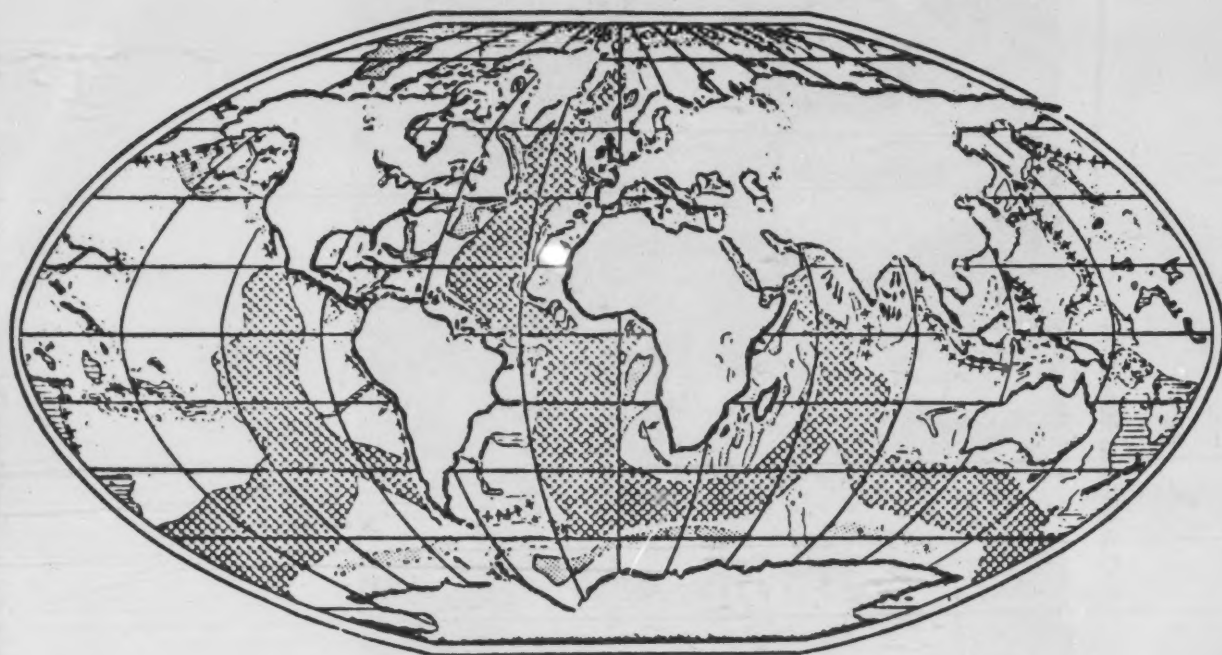


FIGURE 7. THE FOUR OCEAN PROVINCES

NUCLEAR SAFEGUARDS

By
JAMES F. NEY

Division Supervisor
Nuclear Security System Studies Division
Sandia Laboratories
Albuquerque, New Mexico 87115

NUCLEAR SAFEGUARDS

Abstract

Because of the increasing incidence of terrorism, there is growing concern that nuclear materials and facilities need improved physical protection against theft, diversion, or sabotage. Physical protection systems for facilities or transportation which have balanced effectiveness include information systems, access denial systems, adequate and timely response, recovery capability, and use denial methods for despoiling special nuclear materials (SNM). Sandia Laboratories has a major U.S. Energy Research and Development Administration (ERDA) role in developing advanced physical protection systems for improving the physical protection afforded SNM during transport and at facilities. Improved physical protection equipment such as perimeter and interior alarms, secure portals, and fixed and remotely-activated barriers is being developed and tested. In addition, complete prototype protection systems are being developed for representative nuclear facilities. A plutonium item protection system has been designed which provides improved protection for stored plutonium against a forceable attack or diversion attempt. The ERDA safe-secure transportation system for highway shipments of all significant quantities of nuclear material utilizes special penetration-resistant and self immobilizing vehicles, special tactical escort vehicles with trained escort personnel and a nationwide dedicated communication system for monitoring the status of all shipments.

To determine the effectiveness of these improved physical protection systems, two evaluation methods are used. Computer models have been developed which aid in identifying critical attack scenarios and then simulate such scenarios. The simulation model allows alternative system designs to be evaluated for cost-effectiveness against a range of threats. The second method involves the actual testing of elements of protection systems. This method, called adversary simulation, utilizes teams of security-cleared individuals who develop attack or diversion scenarios and attempt to carry out these plans. An example of adversary simulation was a test conducted utilizing an Explosive Ordnance Disposal (EOD) team who were professionals in the use of various hand and power tools as well as explosives. The team was challenged to penetrate, in minimum time, a 7-foot high by 7-foot wide by 14-foot deep section of a foam filled storage structure. The team spent 14 exhausting hours trying to penetrate to the rear of the structure.

Introduction

As you are well aware, acts of terrorism have increased considerably over the last decade. This is illustrated by Table I, which summarizes international terrorist incidents from 1968 through 1974. The term, "international," refers to incidents which clearly transcend national boundaries. For example, the activities of the Symbionese Liberation Army in the state of California would not be included, while a bomb blast at the Lebanese consulate in Los Angeles would be. Thus, the total number of violent acts is considerably larger than shown in Table I. The decrease in aircraft hijackings is of interest. It is attributable not only to increased airport security but also decrease in international tolerance of hijacking.

While the nuclear industry has not been a target of terrorist acts except in a few minor incidents, there is a growing concern that the physical protection afforded nuclear materials needs to be improved. Most notable of the incidents involving the nuclear power industry was the August, 1975 bombing of the water intake at the power generating station in Monts d'Arree, France. A local anarchist group, the Liberation Front of Brittany, has been reported as being responsible for this bombing. While this incident resulted in no hazard to the public, it emphasizes the need for measures to prevent more serious consequences.

The materials requiring the greatest protection are plutonium and highly enriched uranium. Both have received a great deal of publicity as materials that can be used in the fabrication of a crude nuclear explosive, or in the case of plutonium, used in a radiological dispersal mode. Figure 1 illustrates the projected growth in quantities of Special Nuclear Material (SNM) in the United States nuclear power fuel cycle. At present, the material of primary concern is the plutonium being converted from natural uranium in existing light water reactors. Since spent fuel is presently not being processed, the contained plutonium is self-protected by the high radioactivity of fission products, as well as being in a very dilute form. Typical plutonium to total mass ratios for spent LWR fuel are about 1:200. Once reprocessing of this fuel takes place, both of these inherent protection mechanisms are no longer available. High temperature, gas-cooled reactors (currently not being actively developed) utilizing highly enriched uranium as a fuel, and eventual recycling of uranium-233 (converted from thorium) may add to the materials inventory of concern. Eventually, the liquid-metal fast-breeder reactor program will cause a further increase in the amount of plutonium being used,

stored, and transported. Willrich and Taylor¹ stressed that before plutonium reprocessing is undertaken on a major scale and before plutonium recycle begins, the worldwide nuclear industry should assure that adequate physical protection safeguards are in place to protect against malevolent actions involving special nuclear material.

The predominant threat that is postulated is an overt attack by a well-organized, armed group with sufficient strength to overpower conventional security guards and security hardware. Potential attributes of such a group are listed in Table II. Such a group could also be in collusion with employee(s) having access to nuclear material or to vital nuclear system components. The decision diagram shown in Figure 2 illustrates the elements of a physical protection system for dealing with such threats. The combination of all these elements results in protection systems of balanced effectiveness. Detection, communications, delaying mechanisms, and response forces collectively act to prevent loss of the material while an adequate recovery capability assures timely recovery if material is lost. If all these fail, then use denial techniques will make it difficult for the attacker to use the materials. A balanced system comprised of these elements when combined with appropriate positive publicity can result in psychological deterrents. Thus, as indicated in Figure 2, there are five levels at which a malefactor action may be thwarted.

For either transportation or facilities, each element of a security system plays an important role in reducing overall risk due to malevolent

1. Nuclear Theft: Risks and Safeguards, Willrich, Mason and Taylor, Theodore B., Ballinger Publishing Company, Cambridge, Mass., 1974, 252 pages.

usage of nuclear material. This risk can be thought of as being made up of four multiplicative factors: (1) the frequency of attempted theft, diversion of nuclear material, or sabotage, (2) the likelihood of successful theft, diversion or access to vital components given an attempt, (3) the likelihood that malevolent acts which endanger public safety can be accomplished in the event theft, diversion, or access occurs, and (4) the cost of such malevolent acts. A balanced physical protection system acts to reduce each of these four major risk factors.

First, a comprehensive system in which all elements are balanced, i.e., no weak links, leads to psychological deterrents which reduce the frequency of attempts by increasing the malefactor's uncertainty and decreasing his confidence. Additionally, an improved physical protection system will force malefactors to commit greater resources with a concomitant increase in the likelihood that their activities will be detected by law-enforcement agencies and nullified before an attack can take place. Second, physical protection systems which include information systems, access denial systems, and adequate and timely response, all serve to reduce the likelihood of successful theft, diversion, or unauthorized vital access if attempted. Third, special recovery technology and procedures, use denial methods for despoiling special nuclear material, and sabotage-resistant equipment and facilities act to reduce the likelihood that a malefactor can threaten society with a consequence even if he has successfully stolen or diverted material or gained access to vital system components. Finally, the cost which would result if the protection system should fail may be reduced in many cases by special siting considerations and by transportation mode and route selection which serve to minimize the cost associated with a consequence.

It would be desirable if the risk resulting from malefactor actions could be quantified in the manner of the recent LWR reactor safety study of Professor Rasmussen. Unfortunately, many aspects of nuclear theft, terrorism, and sabotage are not quantifiable. Nevertheless, it is useful to understand how the elements of a physical protection system interact with each other to reduce risk in a relative sense. Further, it should be recognized that the physical protection problem will never have a unique, complete solution and that risks can be minimized, but not eliminated, in real-world systems. The required level of protection installed at any given time will be dynamic, depending on the perceived threat, national priorities, and allocation of available resources.

Sandia Laboratories is engaged in a continuing program, sponsored by the Energy Research and Development Administration, to develop and apply advanced technology to the protection of nuclear materials during transit and at fixed locations and to develop methods to assess the effectiveness of physical protection systems.

The overall safeguards approach described above is being pursued. A major strength of this approach is that malefactors must carry out a sequence of actions successfully, while the safeguards system need only interrupt the sequence at some one point prior to sequence completion by the malefactor. This has been referred to as "defense-in-depth" and it means that an effective safeguards system is not dependent on every element being 100-percent effective; rather, there is a high degree of redundancy in the system. Special attention is also being given to protecting employees against duress and blackmail situations.

Transportation

An example of current physical-protection safeguards is the nationwide ERDA safe-secure transportation system for highway shipments of all significant quantities of government-owned special nuclear materials. The ERDA system incorporates special penetration-resistant and self-immobilizing vehicles, special tactical escort vehicles with trained escort personnel, and a nationwide dedicated communications system for monitoring the status of all shipments. Efforts to develop vehicles which would greatly improve the security and safety of nuclear weapons and materials during surface transportation were begun over 5 years ago. The effectiveness of the system was to be such that diversion of the cargo by unauthorized persons could be delayed until response and recovery forces could arrive and regain control of the shipment.

Safe-secure trailers (SST's) which have been in operational use by the ERDA since October 1972 are 40-foot-long, 8-foot-wide, 12½-foot-high closed trailers and, as shown in Figure 3, are similar in appearance to a standard semitrailer. The walls, ceiling, and floor are constructed of materials which will resist penetration attack for extended periods of time. The SST includes internal deterrents and an immobilization system to preclude moving the trailer in the event of an attack. Since becoming operational, the present SST fleet has accumulated nearly one million miles of service. A second-generation safe-secure trailer (SST-2) has been developed and is currently being procured to expand this system to handle all government-owned special nuclear material in significant quantities. The new trailer is based on the original design but incorporated additional major protection improvements. The towing tractors include armor for crew and equipment protection.

Special tactical escort vehicles, similar in appearance to standard recreational vehicles, will provide protection for escort couriers and vital equipment, as well as afford sufficient comfort to assure that couriers remain alert during long road trips.

A van-body truck is also being developed to provide a smaller vehicle which incorporates penetration resistance, immobilization, access control, driver protection, and communications.

A nationwide voice communications system, which allows continuous contact with ERDA shipments and escorts in the contiguous United States is shown schematically in Figure 4. It has been operational since 1972. Because of the voice mode, the number of shipments that can be monitored at any one time is limited. To alleviate this limitation, increase reliability and decrease vulnerability, a digital communications system has been developed and tested. This system, which began limited operation last fall, is capable of monitoring up to 100 convoys with present reporting procedures. Looking ahead, the digital system is the key to reducing dependence on human inputs in future improvements.

In the event of an attack on an SST convoy, the escort courier force has primary responsibility for preventing unauthorized convoy control. In order to determine if an adequate backup protection is available along all shipment routes, a national assessment of U. S. State police capabilities has been completed and a similar assessment of local law-enforcement capabilities is planned. This data is being computerized and will be an integral part of the communication and control system operations.

The current system depends on the escort couriers to report convoy location and pinpoint an incident. Since this could lead to some uncer-

tainty in location, a system is under development which will regularly and automatically report the actual locations of the convoy. The system, called Hi-Note, is shown conceptually in Figure 5. It will take advantage of the existing Omega worldwide navigational system. Receivers on the shipment truck will continually monitor phase difference information from three of the network stations. On interrogation by the home base or at specified intervals, the necessary information will be relayed from the truck to a central ground station where a computer will make the necessary calculations to determine convoy location. Accuracies of one nautical mile during the day and 2 nautical miles at night have been demonstrated.

Efforts are also underway to improve the safety of air shipments. Airborne shipments are very difficult to hijack without employee collusion, but the enormous kinetic energies involved in aircraft crashes may scatter radioactive material either from the impact, the ensuing fire, or from both. Accident resistant containers, Figure 6, for both fixed and rotary wing aircraft are being developed. The larger system is designed to survive the effects of a 190-mph impact and an ensuing 3-hour fire at 1850°F black body, which are environments expected as a result of a fixed-wing aircraft crash. A smaller version, designed for rotary-wing use, is designed to survive a 95-mph impact, followed by a 1½-hour 1850°F fire.

Facilities Protection

Safeguards systems are also being designed for facilities protection. Facilities that must be protected include power reactors where the primary threat is sabotage that would result in the release of

radioactivity, and material handling facilities such as nuclear material storage, spent fuel processing, fuel fabrication and research sites where both sabotage and overt or covert theft of nuclear materials must be considered. Collusion or duress, leading to compromise of the system from within, must be anticipated and protected against. The scope of the Sandia effort ranges from the evaluation and improvement of such general-purpose functions as personnel access control to the development and operational evaluation of complete prototype advanced protection systems installed at representative operating facilities.

In general, some of the broad improvements that can be implemented at facilities include (1) improved guard tactics, training, and weapons, (2) improved guard protection, (3) improved detection systems, (4) a balance between delay and response time, (5) separation of materials control and accountability documentation, and (6) continuous real-time nuclear material inventory. In support of this, hardware and supporting technology development are underway in the following areas: improved countermeasure-resistant perimeter and interior alarms and assessment equipment; remotely-operated personnel and material control portals; fixed and remotely-activated barriers; item accountability and control systems; centralized data processing and display equipment; SNM use-denial methods; and guard effectiveness improvements. Existing new hardware is being subjected to performance and vulnerability tests as part of the ERDA protection equipment certification program.

At the same time, design, installation, and operational testing and evaluation of balanced, integrated systems are being undertaken at representative facilities, including a plutonium storage area and a research reactor. As an example, Figure 7 shows a prototype protection

system which is being designed for installation in a plutonium storage facility. The objective of this program is to evaluate, under field operational conditions, a greatly improved system for the physical protection of nuclear material, both in storage and handling. Design objectives include: (1) real-time material monitoring to provide immediate detection of loss; (2) central control to separate accountability and access control from direct physical access and thereby minimize potential for employee collusion; (3) limitations on the quantity of SNM released in a single transaction and on the frequency and duration of access; (4) graduated and balanced protection so that the most potentially hazardous material is under the highest security level; (5) the use of multiple, independent subsystems to assure protection in depth against failure or defeat of individual elements; and (6) provision for protection during both normal and emergency conditions.

The storage building is designed to delay forcible entry. The material in the building is stored in secure-storage modules, as shown in Figure 8, that will control access and maintain accountability during normal operations, as well as provide additional delay to forcible intrusion. Each module consists of an 8-inch thick reinforced concrete cubicle with an alarmed vault-type door that houses a carrousel. The SNM containers are staggered on the carrousel so that only a single container can be removed from the access slot when the module door is unlocked. All material will be continuously monitored while in storage and all access will be remotely verified and controlled from the material control and accountability center. Accountability information will be transmitted by a secure communications system to a tamper-resistant data processing and display center that will provide real-time item

accountability. Remotely operated portals, credential verification and positive personnel identification systems will be integrated into the system. The security control center will not take part in normal operations; rather security response will be triggered only if deviations from normal operations are indicated.

Evaluation

To evaluate the level of protection afforded by techniques such as those previously described, analytical evaluation methods are being developed and systems and subsystems are being subjected to adversary simulation testing. A facility computer simulation model has been developed for the purpose of allowing alternative facility protection systems to be evaluated for cost-effectiveness against a range of threat levels constructed from the attributes of Table II. Site characteristics are broken down into barriers, on-site guards, and off-site guards. The barriers are specified by number, alarm, type, and thickness. Guard forces are characterized by number, response time, armament, and dedication levels. Then, critical attack paths corresponding either to the shortest potential delay times after detection or to the fewest number of detection elements, are identified. Depending on the site complexity or the precision desired, this may be done either by inspection and judgment or by event-tree modeling and assessment of all possible attack paths through the protection system array facing either external or internal malefactors. Figure 9 represents a hypothetical model of a facilities design as viewed along one such critical attack path. For example, Barrier 1 might be a four-strand fence which defines the site boundary, Barrier 2 a double

chain-link fence which serves as a protected area boundary, Barrier 3 a vehicle barrier, while Barrier 4 could bound a material access area (MAA), or vital area and be made of thick reinforced concrete. Barrier 5, which might provide additional delay, is activated by alarms mounted on Barrier 4. For this hypothetical reference design, the site is assumed to have a five-man special weapons and tactics team (SWAT) that can respond in about 7 minutes and an additional five-man backup force available in 15 minutes. An off-site, ten-man SWAT team can arrive in about 60 minutes. Time delays for barrier penetration and for response force arrivals are described probabilistically, as are the likelihoods of alarms being triggered. Guard and television surveillance may result in an alarm with a random probability. Times required to carry out sabotage or theft, once access to the vital area or MAA is gained, must be specified as functions of malefactor force levels.

Given such inputs, the computer simulation model which has been developed can be utilized to simulate many different adversary attacks. The general operational procedure of the model is shown in Figure 10. After the site characteristics have been selected, adversary attributes are generated and an attack is simulated. Barrier breaks, delays of barriers, crossing times between barriers, and advancements are simulated by a random sample from the appropriate distribution functions. Alarms at a given barrier may trigger communications to the on-site guard force which (1) goes to the alarm point and assesses the disturbance, (2) calls backup and off-site forces if a malevolent action is underway, and (3) engages the attackers in either a direct confrontation or a delaying (sniping) mode. Guard and response force engage-

ments with attackers are simulated by a modified Lanchester model. Results of Vietnam ambush experiences are being studied and compared with the results predicted, using this simulation. This comparison will be used to determine if additional modifications to the code are necessary. If the attacker wins the engagement as a result of the simulation, then his advancement continues until interrupted by the arrival of additional guards and subsequent engagements. The simulation ends with the defeat of the attackers or the completion of theft or sabotage. Then a new and different attack is generated against the site along this same attack path.

After a large number of different attacks have been simulated, 300 or more, statistics can be accumulated which permit characterization of the protection system's effectiveness for the critical attack path being investigated. The entire process is repeated for different critical attack paths in order to establish the effectiveness of the reference protection system against various levels of threat. Then, elements of the protection system can be selectively changed and the simulation calculations repeated to determine the relative effectiveness of alternative designs. Table III illustrates the types of tradeoffs which can be investigated with such a model for the attack path of Figure 9. It is envisioned that this computer simulation model will enable cost-effective designs of facility protection systems. Since the computer model considers many variables as statistical processes, the output of the model is of a probabilistic nature which, in many ways, reflects the real-world situation where nondeterministic factors play a strong role in the outcome of an actual incident.

Physical protection systems can be independently tested and partial validation for the simulation model provided by the technique of adversary simulation. Adversary teams with a wide range of skills and technical backgrounds are used to ferret out weaknesses in systems or hardware. Such a team, made up of security-cleared individuals, is given a data package which it might be able to collect after extensive surveillance of the system. Some teams may be given insider information. They are then tasked to develop attack or diversion scenarios and to assess both by analysis and laboratory experimentation their likelihood of defeating either the total protection system or given elements. The scenarios and experimental results are then examined by the system designers and corrective measures are taken when required. In addition to an independent test of a security system's effectiveness and validation of the computer model, such testing provides necessary data on penetration times and detection probabilities.

As an example of adversary simulation, a test was conducted in 1970 to evaluate the utility of low-density polyurethane foam in denying unauthorized access to nuclear materials. The test was conducted utilizing an Explosive Ordnance Disposal (EOD) team with personnel from each of the military services who were professionals in the use of various hand and power tools as well as explosives. In particular, the team was challenged to penetrate in minimum time a 7-foot high by 7-foot wide by 14-foot deep section of a foam-filled storage structure commonly called an igloo. All tools the team desired were provided to them for use during the test. After 14 hours of effort with a variety of tools and techniques, the team

penetrated 14 feet into the igloo and gained access to the container. This early test revealed that systems can be designed which will delay access to nuclear materials for extended periods. Knowledge gained from this and many subsequent adversary tests has been incorporated in security systems now in use for protecting special nuclear materials.

Summary

In the development of physical protection systems, objectives for improving overall performance include the following: (1) Increase the time required for the malefactor to achieve his goal; (2) decrease the time required for detection of malevolent activities; (3) reduce the time for adequate response force arrival; (4) increase the capability to neutralize the malefactor; (5) reduce the total protection system costs, while increasing the level of protection; (6) improve acceptance levels (social, environmental, legal and institutional); and (7) increase nuclear fuel cycle safety.

Fortunately, there is sufficient lead time and technical base to explore and develop new protection system concepts so that a completely integrated and tested protection system capable of providing unprecedented levels of security can be available when needed. Although it will be impossible to completely eliminate all risks, it should be both possible and economically feasible to install protection systems which will deter or prevent a malefactor from using the nuclear fuel cycle to disrupt society.

TABLE I

SUMMARY OF INTERNATIONAL TERRORIST INCIDENTS
--

YEAR	NO.	INCIDENTS WITH FATALITIES & INJURIES		INCIDENTS WITH RANSOM PAID DEMAND/PAID		SUCCESSFUL AIRPLANE HIJACKINGS	NO. WHEN KNOWN	
		NO. KILLED/WOUNDED		NO. (million \$)			AVG	MAX
68	35	6	21/71	0	0/0	5	3.0	6
69	51	4	5/35	0	0.3/0	25	3.0	13
70	101	14	74/71	3	1.45/0.25	45	4.6	10
71	52	4	7/12	4	0.5/0.1	13	3.0	6
72	81	26	236/123	13	11.3/9.9	13	4.4	19
73	163	32	92/479	25	61/37	10	3.7	17
74	151	69	441/1124	4	72.2/78.9	5	3.5	8
75	89	43	92/426	5	6.6/0.3	1	6.4	40

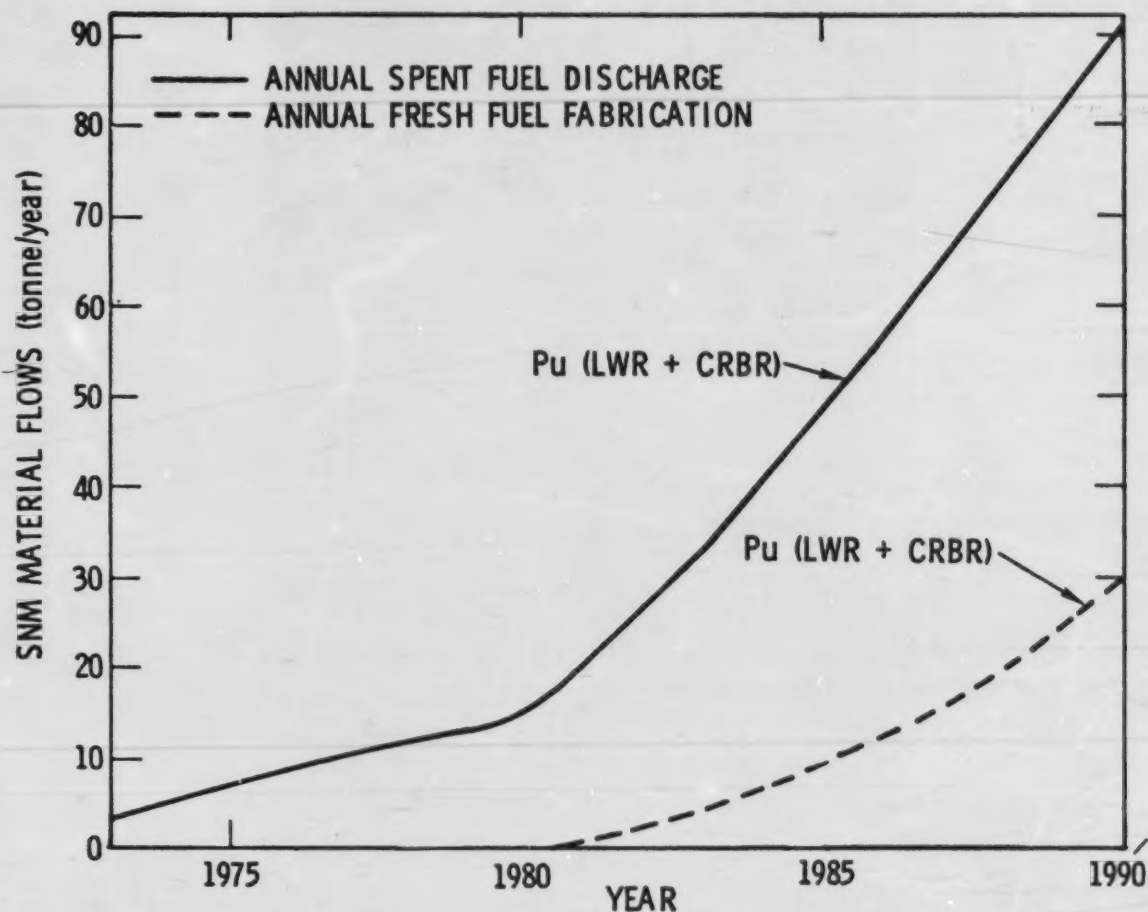


FIG. 1 Annual quantities of SNM projected to flow in US nuclear power fuel cycle. The following were used in constructing the figure: ERDA Office of Planning and Analysis latest projection for nuclear power distribution; plutonium recycle is initiated in 1982 and utilized in 25% of US light water reactors in 1985 and thereafter; Clinch River Breeder Reactor (CRBR) operation in 1982, and no US commercial LMFBR plants before 1993.

TABLE II. POTENTIAL INCREMENTAL MALEFACTOR ATTRIBUTES

NUMBERS

- Number of People Independent of Other Factors

KNOWLEDGE

- Casual
- Public Research
- Criminal
- Intelligence & Insider

EQUIPMENT

- Hand Tools
- Power Tools
- Explosives
- Heavy Equipment
- Specialized

DEDICATION

- Casual
- Injury
- Loss of Life

ARMS

- Small Arms
- Explosives
- Automatic Weapons
- Tanks

TRAINING & PLANNING

- Planning Level
- Degree of Training
- Tactics

TRANSPORT

- Foot
- Car or Truck
- Aircraft
- Special

INTENT

- Theft
- Sabotage

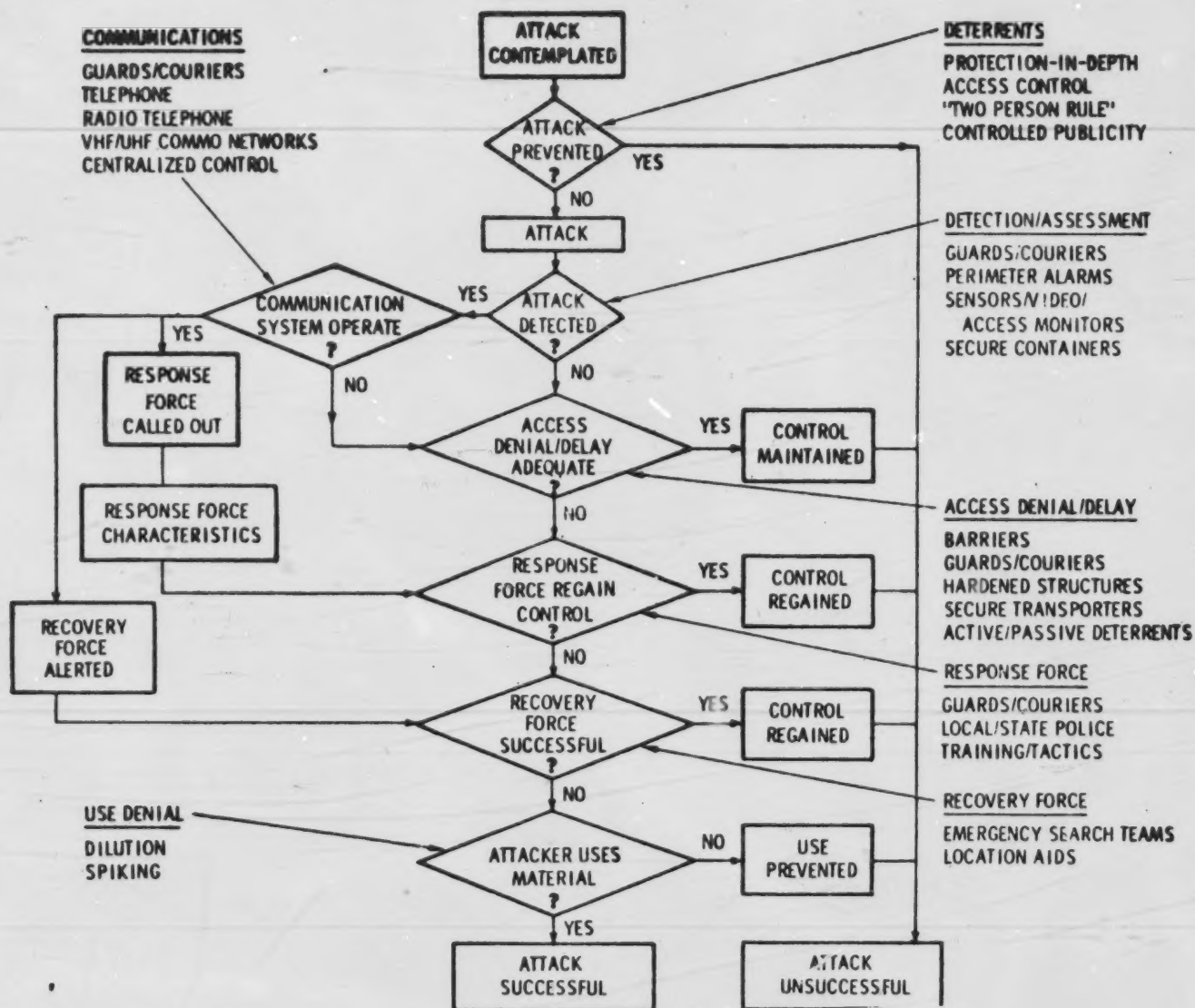
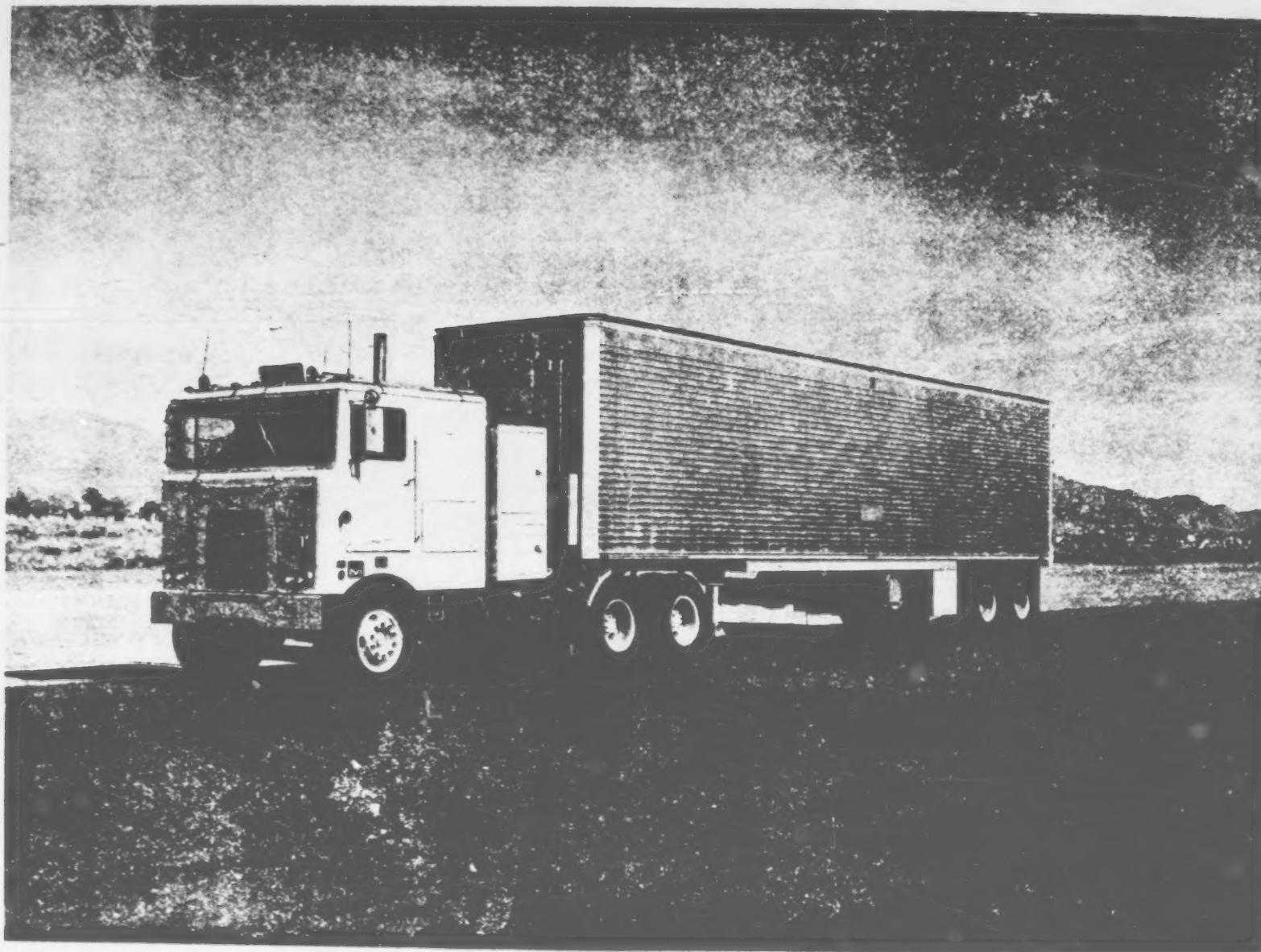


FIG. 2 Decision diagram illustrating physical protection system elements for facilities and transportation.

-327-



352

FIGURE 3

353

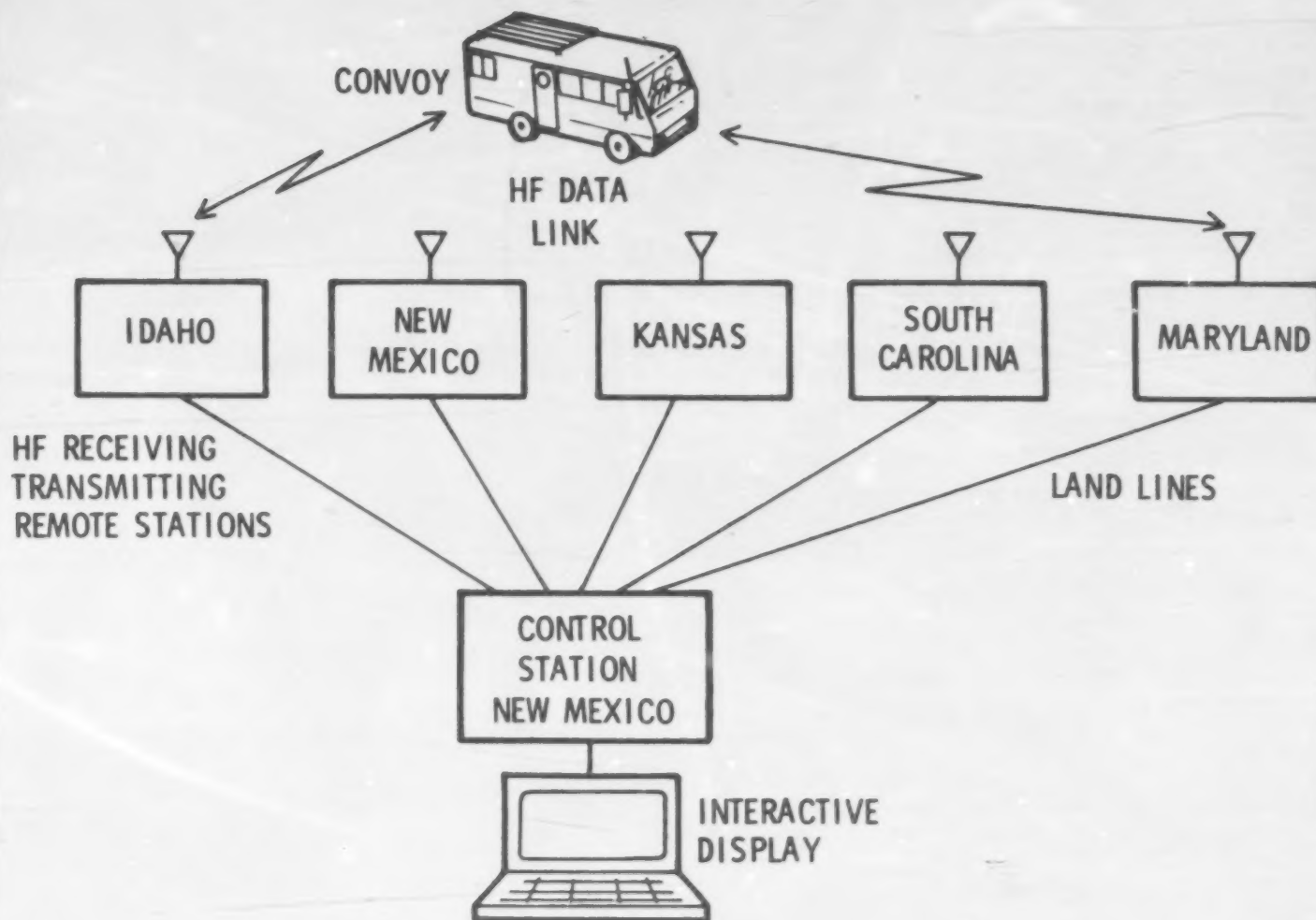


Figure 4. ERDA nationwide communications system for SNM transportation.

PRINCIPLES OF HIGH NOTE OPERATION

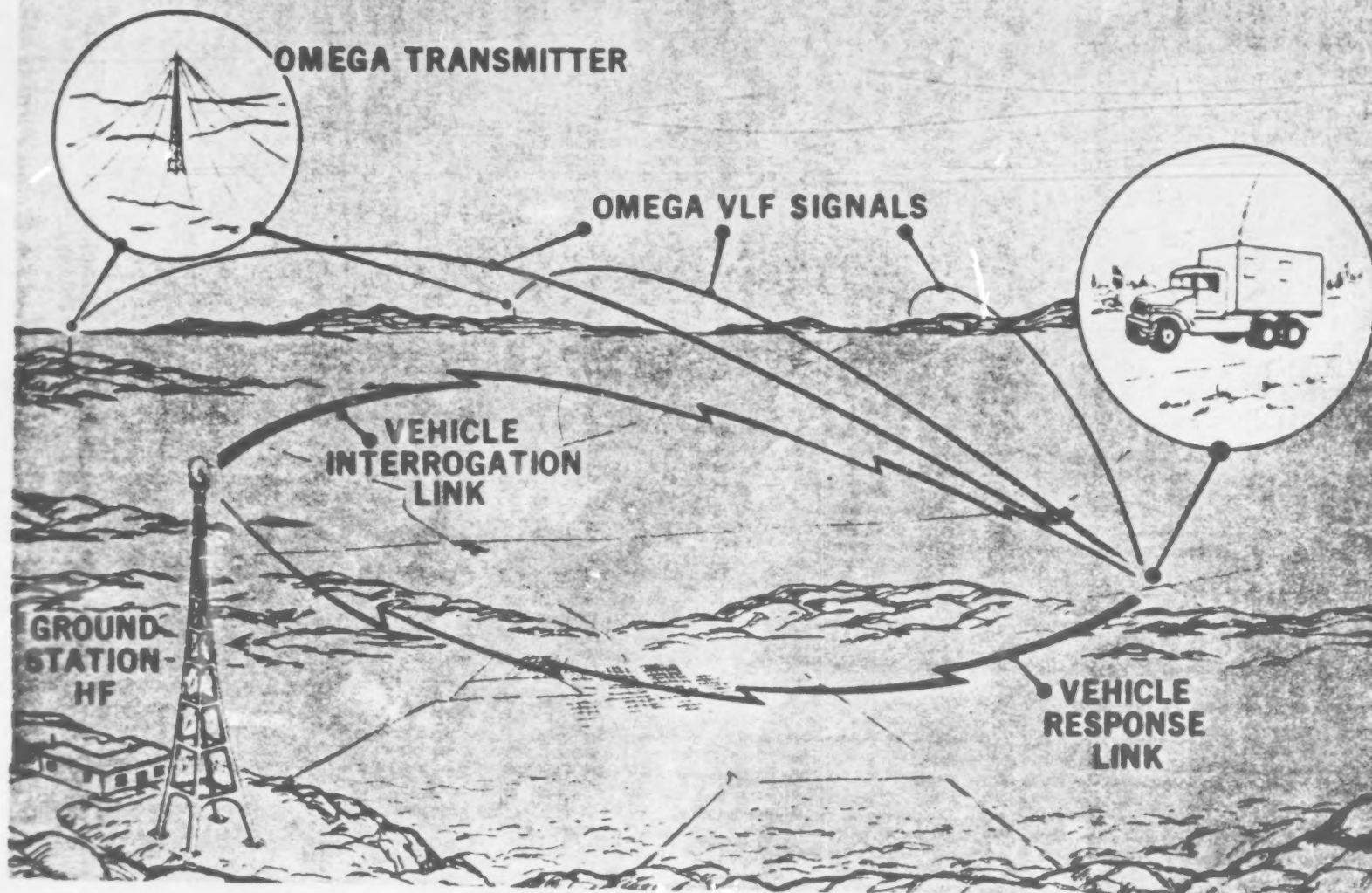


FIGURE 5

**GRAIN ORIENTED
RADIAL
ENERGY ABSORBER**

**GRAIN ORIENTED LONGITUDINAL
ENERGY ABSORBER AND FIRE BARRIER (WOOD)**

RIGID INNER CONTAINER

STAINLESS STEEL JACKET

PAYLOAD SYSTEM

INNER DOOR

BOLSTER

**VIBRATION
ISOLATOR (4)**

WOOD FILLER

OUTER DOOR

HELICOPTER ACCIDENT RESISTANT CONTAINER WITH TYPICAL PAYLOAD

FIGURE 6

-330-

357

358

ITEM CONTROL SYSTEM-PLUTONIUM

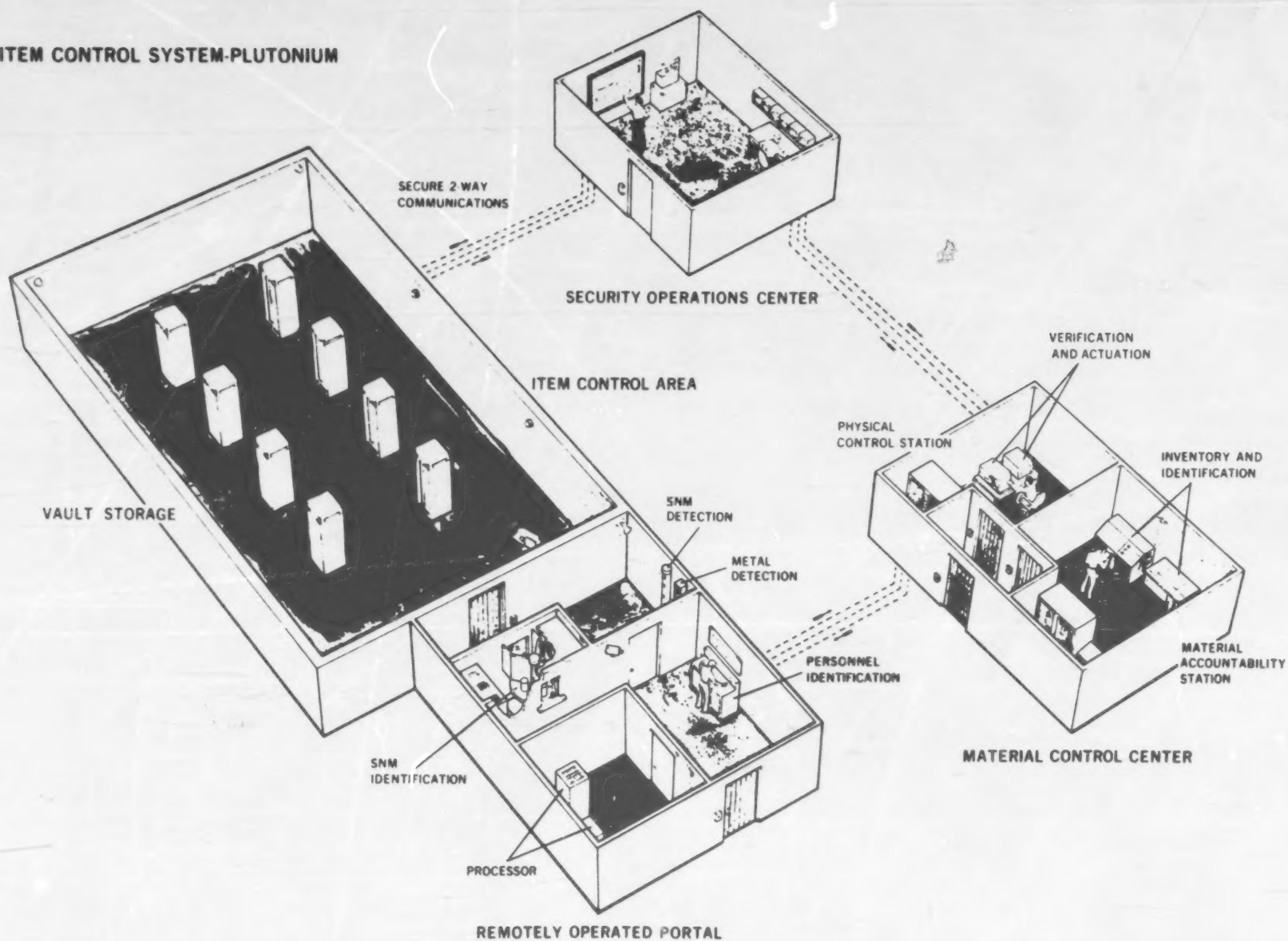
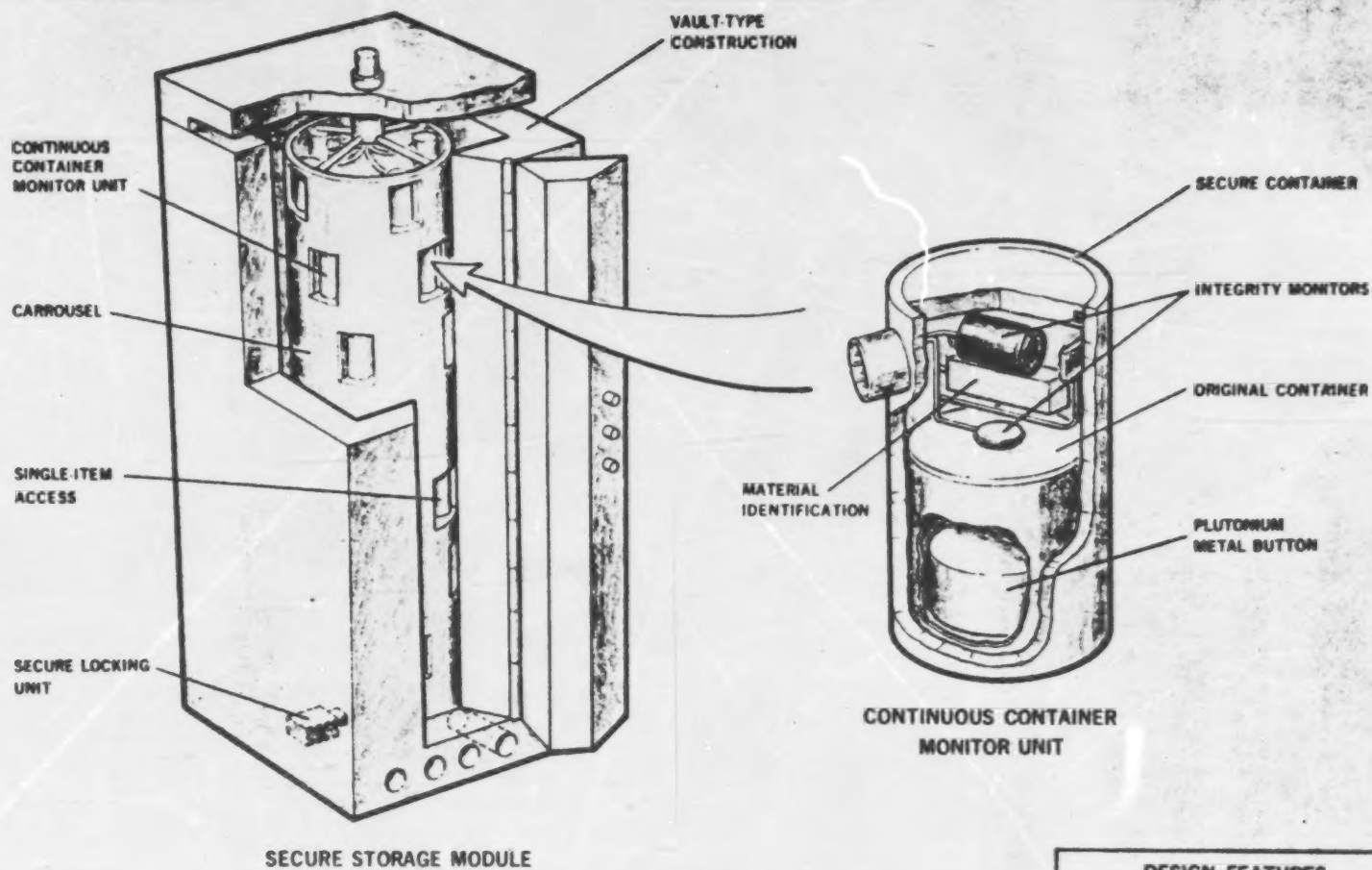


Figure 7. Improved item control system for SNM storage vault.

-332-



SNM ITEM STORAGE AND MONITOR SYSTEM

FIGURE 8

DESIGN FEATURES

- REDUCED VULNERABILITY TO FORCIBLE ATTACK
- RESTRICTION OF AUTHORIZED ACCESS TO ONLY DESIGNATED SNM
- REAL-TIME STORES MONITORING
- REDUCED RADIATION EXPOSURE

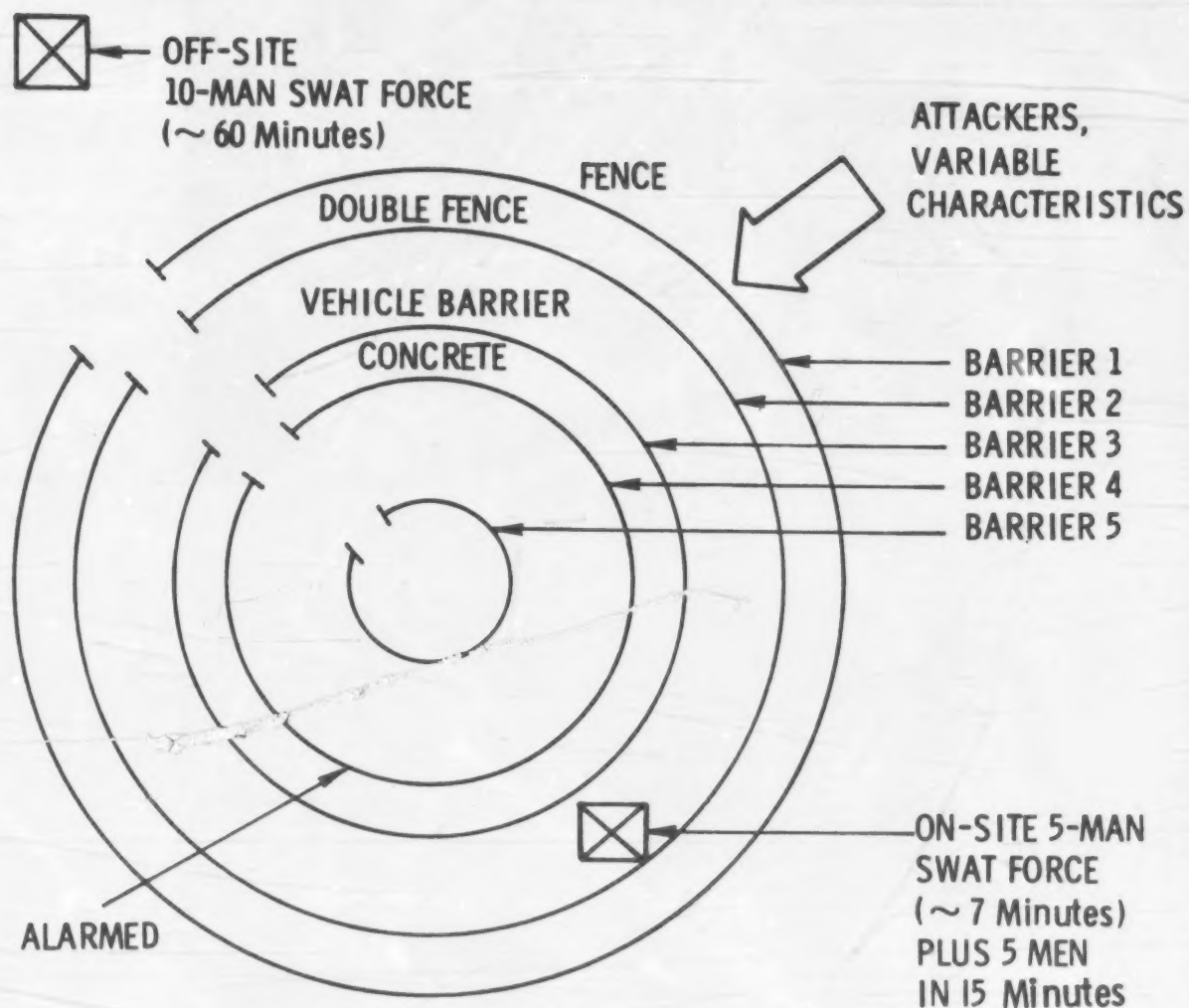


Figure 9. Model of a facilities design for computer simulation of effectiveness.

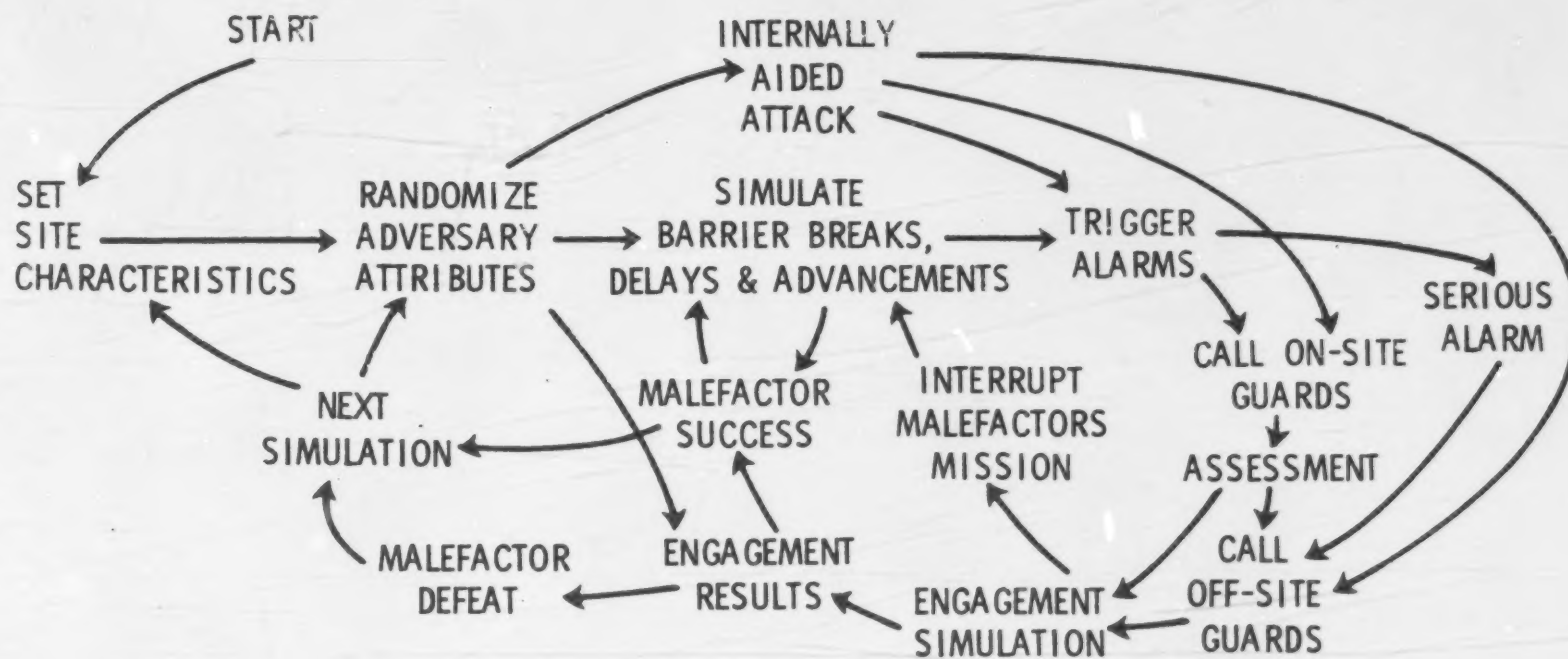


Figure 10. Facilities Computer Simulation Model Operation

TABLE III. RELATIVE EFFECTIVENESS OF AN EXAMPLE FACILITY
DESIGN AGAINST 8 TO 13 ATTACKERS

<u>Protection Design</u>	<u>Conditional^a Probability of Successful Theft</u>	<u>Ave. No. of Successful Thieves</u>	<u>Conditional^a Probability of Successful Sabotage</u>	<u>Ave. No. of Successful Saboteurs</u>	<u>Incremental Annual Cost Over Reference Design^b</u>
Case 1 Reference Design	.02	13	.04	12.5	Reference Design
Case 3 No Off-Site Response	0.3	12.4	0.2	12.6	-\$91,300
Case 10	0	None	.03	12.7	+\$136,000

Barrier 5 delay doubled
Alarm added at Barrier 2

^aDoes not include a threat probability

^bBased on 10-year capital amortization.

NUCLEAR BENEFITS VS. RISKS

By
DR. JOHN W. MCCLUREN

**College of Engineering Sciences (Mechanical)
Arizona State University
Tempe, Arizona 85281**

NUCLEAR BENEFITS VS. RISKS
ENVIRONMENTAL
SAFETY
COST

INTRODUCTION

It is no longer possible for the general public to remain complacent about energy. We must rationally evaluate the energy situation and develop a realistic philosophy. Consideration must be given to the social, economic and biological risks of inadequate energy supplies. The decisions we make about energy will have a direct bearing on the security of our country and the world and the life style of future generations.

The benefits of adequate and properly exploited energy resources will be manifested in economic growth, high industrial and agricultural productivity, improved quality of life and leisure, a more healthful environment and improved ecological conditions. Shortages, wastefulness and unnecessary resource exhaustion may eventually contribute to the degradation of mankind through political conflicts, disease or starvation and poverty. Since energy is the keystone, we must recognize TODAY that there are no energy alternatives. Every existing technology and potential future addition must be researched and implemented to the maximum extent dictated by a realistic assessment of its availability, economics, benefits-risks, environmental impact, and demand.

ENERGY DEVELOPMENT

Figure 1 illustrates how man's use of energy changes as new technologies supplement or replace existing modes. Primitive methods for obtaining energy were either improved or rendered obsolete by scientific

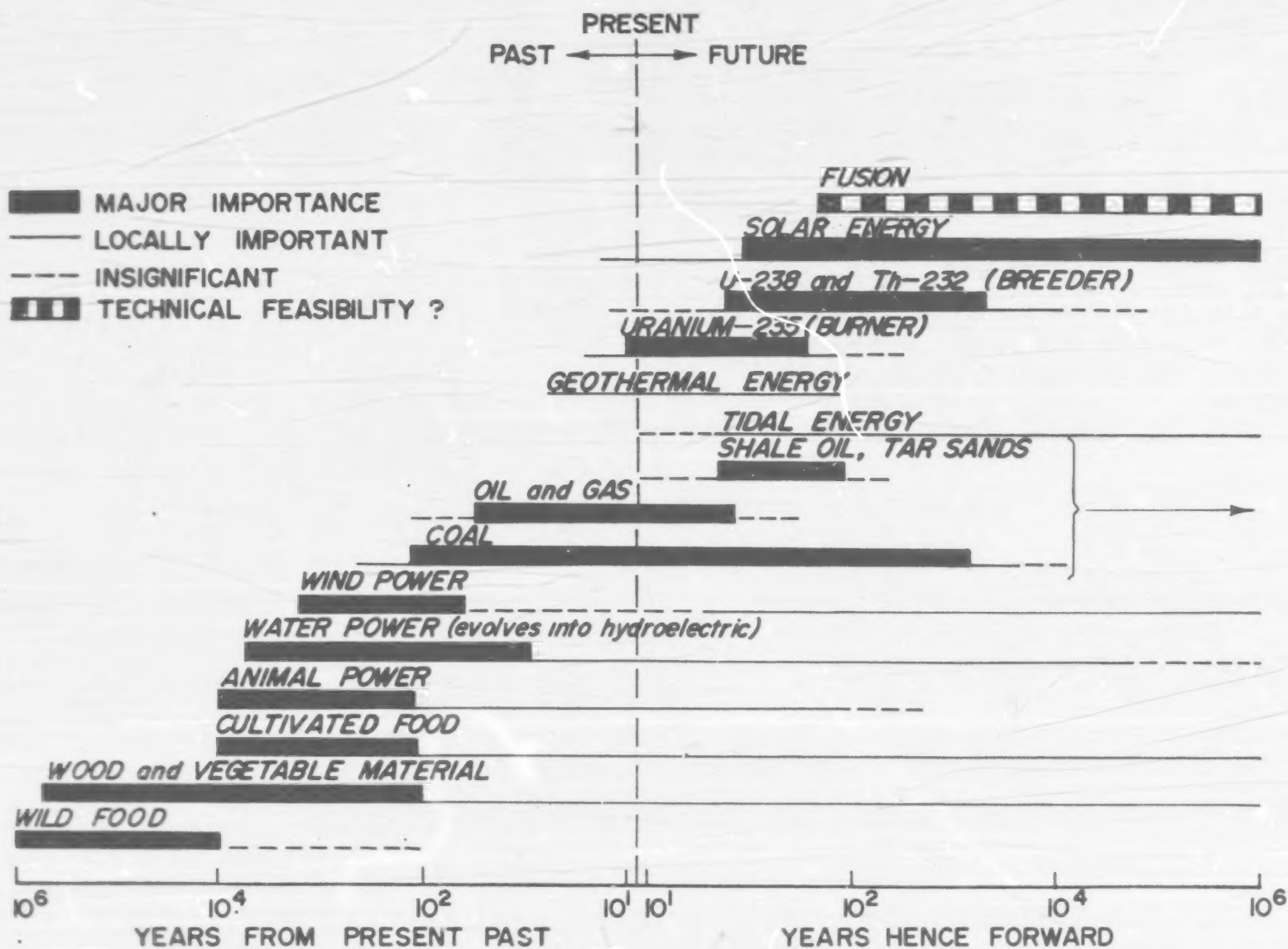


FIGURE I. MAN'S USE OF ENERGY

advances. Many developments were based on economic incentives and the ease in obtaining a particular source. For example, today's energy sources are predominantly the heretofore cheap, abundant supplies of coal, oil, and natural gas. These non-renewable resources can be stretched somewhat (see Figure 2) by the local development of wind, geothermal, solar heating and cooling, and tides. We cannot depend on water power because hydro-electric generation has already reached capacity, at least in most developed countries. The only additional source of energy within our technological grasp as this time is the burner reactor*. We must depend on that and our conventional coal-fueled power plants to bridge the gap to the advanced technologies of breeder reactors, solar power converters and fusion reactors.

Solar power is available today for heating and cooling of buildings, and heating of water. Large scale electrical generation is considered possible but neither commercially nor economically feasible at this time. Utilities in the southwest may be able to use solar electricity to handle daytime peaking loads during summer months by the middle of the next decade. Though expensive, it may compete with oil fired plants. For base-load power generation the costs would be substantially higher because of the need to provide adequate storage of energy for use during periods of darkness and inclement weather. Fusion has several years of research before the break-even point ** can be demonstrated. Scientists have

* Burner reactors fission Uranium-235 to obtain useful energy. Whereas Uranium is the eighth most abundant element on earth only 0.71% is U-235. The remainder is U-238 which does not fission in today's commercial reactors. However, some of the U-238 is transmitted into Plutonium which fissions in the burner reactor and provides a contribution to the energy produced. This reduces the amount of U-235 usage.

** Break-even point occurs when more energy is released by the fusion reaction than used to initiate it. At present about 100,000 energy units must be used to produce a fusion reaction which yields one energy unit.

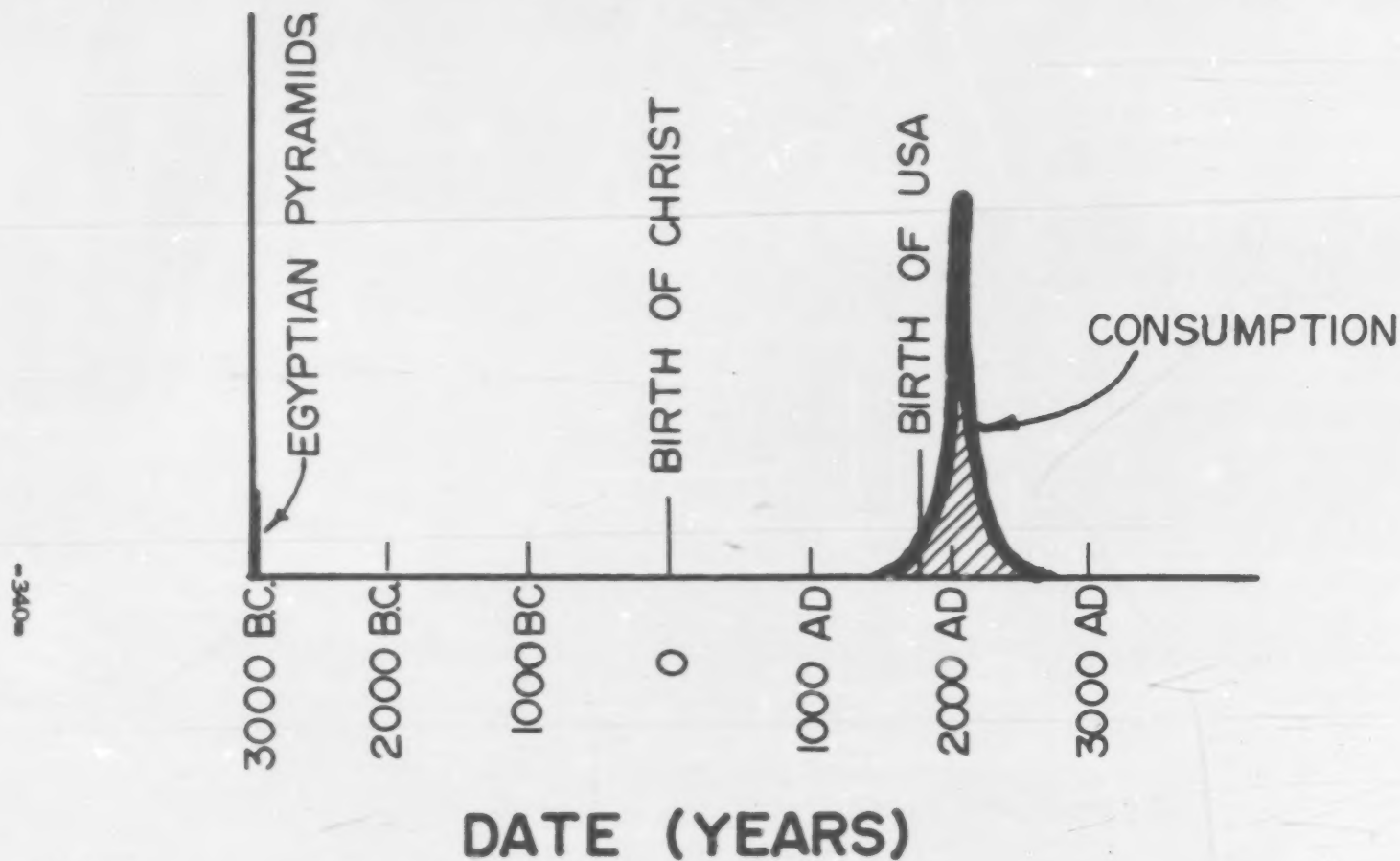


FIGURE 2. CONSUMPTION OF FOSSIL FUELS

numerous radiation and materials problems to resolve. Safety must be investigated. Another area of concern is resource consumption. Will a large scale commitment to fusion exhaust the world's supply of lead for shielding of system components, the supply of lithium which will be used to breed the tritium fuel for the fusion reaction or other materials? Finally, will the concept ever be economically feasible?

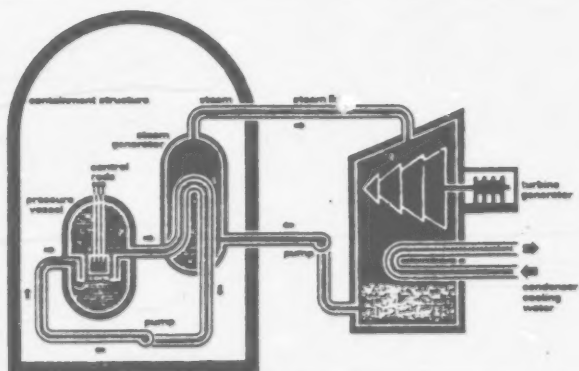
Historically it has taken about twenty-five years to develop a concept into a commercial power supply. For example, the first nuclear chain reaction was achieved by man in 1942*. During the 1950's nineteen different reactor systems were considered for commercial usage. Each had special advantages that their proponents felt would provide attractive low-cost power. Eleven reached the point where experimental reactors were built. Some used gas, others liquid metal, molten salt, etc. Commercial electricity was achieved on a very small scale in Russia, 1954, and the United States, 1957.

* In Gabon, Africa chain reactions were achieved in nature about 1.8 billion years ago. At least six reactors, in different areas of a massive uranium deposit, are known to have operated intermittently for about 100,000 years. The concept is fascinating and reports are appearing in the technical literature. Noteworthy is the study of fission products which revealed that many of the radioactive wastes, particularly plutonium, did not migrate from the site of its creation.

Eventually water cooled reactors* evolved as the most attractive while others were found infeasible due to design, economic problems or need for long term research and development. By the late 1960's large commercial reactors were coming into their own as a safe reliable source of power. However, the early economic incentives disappeared until the 1972 oil embargo which caused dramatic increases in coal and oil prices. Additional incentives appeared as the capital costs of coal plants increased substantially due to the inclusion of environmental control equipment. In any event, it has taken about twenty-five years to develop nuclear power, and this is about the average for any technology. The current status of several proposed technologies are summarized in Table 1.

* Water passes through reactor, picks up the energy released by fission and is heated. The end product is steam which rotates a turbine to produce electricity. U.S. reactors are either pressurized water reactors (PWR) or boiling water reactors (BWR) as shown in the schematics.

Pressurized water reactor (PWR)



Boiling water reactor (BWR)

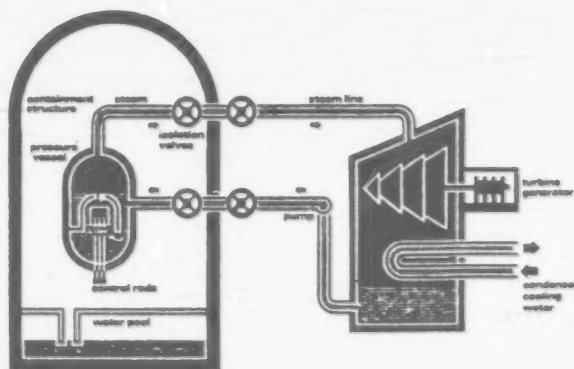


TABLE 1. CONCEPT → COMMERCIAL PLANT

YEARS	PROGRESS	TECHNOLOGY
0	CONCEPT ↓	NUMEROUS
3	EXPLORATIVE RESEARCH ↓	SOLAR - OCEAN GRADIENT
5	PROCESS DEVELOPMENT ↓	SOLAR - VOLTAIC FUSION GEOTHERMAL - ALL BUT DRY STEAM
7	PILOT PLANT ↓	SOLAR - THERMAL SOLAR - WIND BREEDER REACTOR - USA SYNTHETIC FUELS
10	DEMONSTRATION PLANT ↓	BREEDER REACTOR - FRANCE, USSR, UK
25 YEARS LATER	COMMERCIAL PLANT	GEOTHERMAL - DRY STEAM LIGHT WATER REACTORS GAS COOLED REACTORS FOSSIL FUELS

Technology development costs for future energy sources are high, but not prohibitive when compared against dollars spent on petroleum imports. Note Table 2.

TABLE 2. TECHNOLOGY AND OIL IMPORT EXPENDITURES

<u>Technology</u>	<u>Estimated Development Cost (\$ Billion)</u>
Commercial Reactors	50+ (already spent)
Synthetic Coal Fuels	18
Breeder Reactor	12
Oil Shale	7
Solar Electric	26
Fusion	High
Oil Imports (1975)	25
(1976 estimate)	35

THE NUCLEAR OPTION

The U.S. is blessed with about 50% of the world's known uranium reserves. This is sufficient to fuel all the burner reactors constructed between now and the turn of the century for a forty year plant lifetime. Currently, uranium is being mined in several areas of the west. It is also being extracted as a by-product of the super-phosphate fertilizer industry and will soon be removed as a by-product from copper mines. Meanwhile thorium fuel evaluations are underway. This mineral is perhaps three times as abundant as uranium and is found in beach sands. Thorium, like U-238, can be used in breeder cycles, but in this case the fissionable material created is uranium (U-233), not plutonium.

The limited supplies of U-235 make the development of the breeder reactor imperative. Current breeder technology uses liquid metal (sodium) as the material to transfer the heat from the reactor to the secondary systems which produce electricity. There are advantages and disadvantages to this coolant. Advantages include good efficiencies, good heat transfer properties, good nuclear properties, and about a quarter of a century of previous research. Disadvantages include corrosion and radiation damage to reactor materials and requirements to contain the liquid metal in an inert environment. The U-238 fuel has been stockpiled since the 1940's and no mining will be necessary for several centuries. The fuel, stored in warehouses, is available and will be insensitive to increase mining costs and inflation. Eventually, emphasis may be placed on gas cooled (helium) reactors. The technology, however, lags that of liquid metal. Already France, Russia and the United Kingdom have demonstration liquid metal reactors in operation. The French (Phenix') demonstration reactor exceeded project expectations and the first large scale commercial system, the super Phenix', is scheduled to be operational in the mid 1980's, about the same time as the United States' Clinch River Breeder Reactor demonstration plant. Incidentally, the Spanish government is already seriously considering the purchase of a commercial French breeder reactor. The breeder can be thought of as a technology "bird in the hand", but there are "two in the bush"-- solar and fusion.

CONSERVATION

At this point it should be stressed that conservation efforts, either voluntary or legislated, will certainly reduce the increase in United States energy demand. Action will require a conscientious, dedicated effort but will not require altering life styles to achieve the objectives. To determine where results can be maximized, usage should be separated into life-support and life-style energy. Life support energy will always be necessary, but can be used in the most efficient manner. Examples include energy for sanitation, water, housing, refrigeration and processing of food, agriculture and fertilizers, transportation associated with these areas, and health care. Life style energy, on the other hand, can be greatly reduced. This includes clothes drying, night lighted sports events, air conditioning, air transportation, recreation vehicles, tourism, and throw away products. Major savings can be obtained by recycling goods and removing the "design obsolescence" concept from manufactured products. For example, eliminate yearly automobile aesthetic changes and design an efficient, durable vehicle*. Nevertheless, despite all conservation efforts the world's energy consumption will rise because (1) developing countries will require more energy, (2) lower classes are striving to achieve the benefits available to the middle class, and (3) the world's population continues to grow (See Figure 3).

* This approach would require careful planning because of the resulting unemployment in the entire automotive industry.

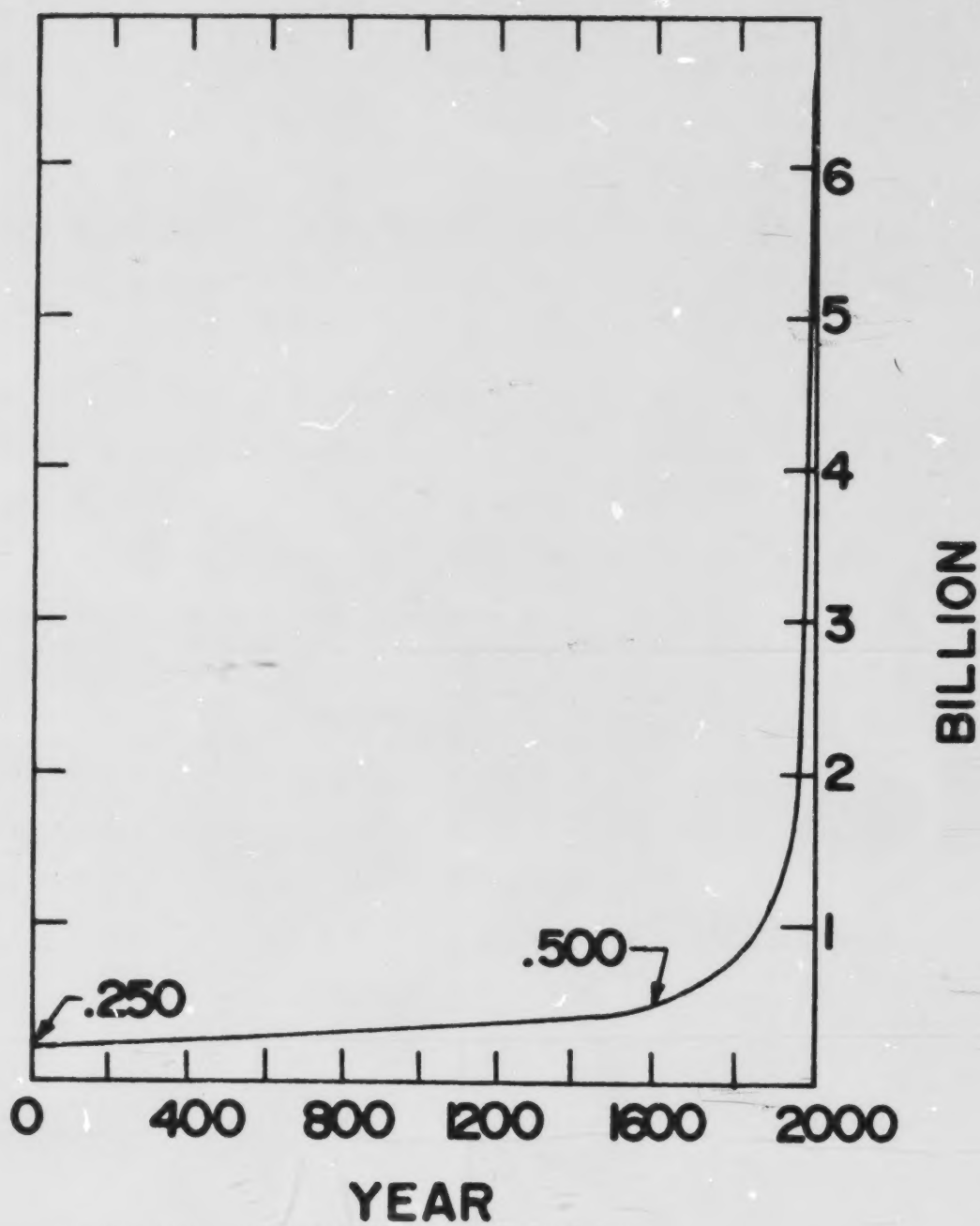


FIGURE 3. WORLD POPULATION

RESOURCES, THE ENVIRONMENT AND NUCLEAR DEVELOPMENT

Environmental effects from energy generation must be considered individually and collectively for each available option. In many areas of the world, particularly where fossil fuels are expensive or in short supply, where hydroelectric has been developed to capacity, or where environmental considerations preclude use of fossil fuels, nuclear energy is playing an ever increasing role. Already Switzerland, Belgium and Sweden generate a greater percentage of electricity on a per capita basis via nuclear reactors than the United States. Belgium, Germany, France and Spain are fully committed while Russia and Italy are heavily committed to electrical generation by nuclear power. Great Britain, however, has been able to temporarily relax the nuclear projections due to development of North Sea oil. Iran, on the other hand, has purchased two reactors from Germany and two from France. Libya purchased one from France. The United States is negotiating sales to Egypt and Israel. Russia is negotiating a sale to Cuba. And so it goes. When the United States refused to sell Brazil a package which included the total nuclear fuel cycle*, because of the potential for proliferation of weapons, Brazil turned to Germany who consummated the deal. When the United States reactor sale to South Africa was recently halted, France got the contract. In addition, France just completed an agreement to sell a reprocessing plant to Pakistan. The United States still appears to have some voice in decisions, however, since diplomatic and economic pressures forced South Korea to agree not to purchase a reprocessing plant

* Uranium, reactors and fuel processing capability. The fuel processing plant can be modified to provide weapons grade materials.

from France. South Korea has purchased two reactors from the United States and one from Canada. Japan, with no fossil fuel, has fourteen plants operating and ten additional units are planned or under construction. Many of the reactors are provided by Japanese vendors.

The United States has experienced overseas reactor sales competition from several European countries and Canada. The Canadian reactor uses natural uranium and heavy water*, an advantage since no U-235 enrichment is necessary. Current United States light water reactors are enriched to less than 5% U-235. Whereas this is far short of the 20%-30% minimum necessary for a crude bomb, enrichment requires energy. For a typical nuclear reactor which produces 1000 megawatts of electricity (serving about one million people) it takes about eight months to two years to repay the energy consumed in mining, enrichment, fuel fabrication, and plant construction. Although this is about the same as for a coal plant, 75% of the consumption in nuclear is for enrichment provided by massive gaseous diffusion facilities**. With improved technology such as centrifuge and laser enrichment, energy requirements will be reduced by orders of magnitude. Although this overcomes some of the Canadian advantages, it will also make enrichment potential easier for other nations to obtain.

Nuclear plants provided 9% of the electricity generated in the United States in 1975, and the replacement by fossil fired plants would have cost

* An isotope of hydrogen called deuterium, abbreviated D. Deuterium is obtained from the ocean and in the future will be used as a fuel for fusion. The Canadians use D₂O instead of H₂O.

** Separates U-235 from U-238. Incidentally, the Oak Ridge gaseous diffusion plant built for weapons program in World War II now sells enrichment services. This has paid for the facility and is enmassing a few million dollars a year profit for the government.

TABLE 3. 1,000 MEGAWATT ELECTRICAL GENERATION

ENERGY SOURCE	ACRES/YEAR CONSUMED	RESOURCES CONSUMED PER YEAR (TOMS)
Coal	1200 (mining)	3,000,000 = 100 car train per day
Oil	Small	2,100,000
Gas	Small	1,800,000
Uranium	25 (mining)	50 tons Uranium to get the 2 tons U-235 which fission & release energy
Hydro	Water Behind Dam	- - - - -
Geothermal	Small provided liquids pumped back into ground	Source gradually depletes and new wells must be drilled
Wind	Enough space for 1,000+ windmills	Average wind must be around 18 mph. Less wind, more windmills.
Solar	40,000 for collectors	- - - - -

- (1) Average values
 (2) Average family of four uses about 11,000 Kw electricity per year. Cost includes capital, overhead, maintenance, fuel, etc.
 (3) 1 Curie - 3.7×10^{10} /disintegration per second.

TABLE 3 continued

	RELEASED TO ENVIRONMENT AT PLANT, TONS UNLESS OTHERWISE STATED (1)	1975 YEARLY ELECTRIC COSTS (\$) (2) FAMILY OF FOUR	1990 YEARLY ELECTRIC COST (\$) (2) FAMILY OF FOUR	REMARKS
Coal	SO ₂ : 130,000 NO _x : 24,000 Particulates: 6,000 (Assuming 97.5% removal efficiency) Arsenic: 0.3 Lead: 3.0 Mercury: 3.0 Radioactivity: 0.3 Curies (m) (Radium, Thorium, etc.)	380	960	-----
Oil	SO ₂ : 54,000 NO _x : 24,000 Particulates: 3,000 (Assuming 97.5% removal efficiency) Radioactivity: 0.003 Curies (Radium, Thorium)	720	Expense high. Availability unreliable	No new plants planned.
Gas	SO ₂ : 10 NO _x : 13,000 Particulates: 450 Radioactivity: None	220	None available	No new plants planned. Price regulated. Supply limited.
Uranium	85 _x & 133 _x : 10,000 Curies PMR Short lived Radioactive Gases: 2,000,000 Curies BWR 131 _i : 0.2 Curies PMR 131 _i : 5.3 Curies BWR Fission & Activation Products: 30 Curies PMR Fission & Activation Products: 50 Curies BWR Tritium: 6,000 Curies PMR Tritium: 100 Curies BWR	265	815	-----
Hydro	-----	220	300	With dams existing in 1975. New hydro plants sometimes more expensive than nuclear plants.
Geothermal	Hydrogen Sulfide Saline Brine Radioactivity Minerals } Site Specific	--	1,390	-----
Wind	-----	--	3,000	Peaking units & small loads like homes, farms etc.
Solar	-----	--	4,400 to 22,000	Peaking units & small loads like homes, farms etc.

U.S. consumers over two billion dollars in higher electric bills, the preponderance of the cost due to fuel. Doubling the fuel cycle cost increases the monthly electricity bill for an average family of four by \$38 for oil, \$18 for coal, and \$6 for nuclear. Possible economic and fuel conservation incentives may be accomplished by recycling the plutonium produced in existing reactors, worth about \$11,000 per pound, and extracting the unused uranium from expended fuel elements. Between 1975 and 2000 the total projected nuclear construction will cost about \$80 billion above capital construction costs for coal plants*. The fuel savings, however, may amount to about \$480 billion, providing a net gain to consumers of \$400 billion (in 1975 dollars). Land reclamation may also contribute to the power generation costs. For example, at a strip mine located in the southwest desert it costs about \$6,000 per acre to reclaim land which previously supported one sheep per sixty-five acres.

ELECTRICAL GENERATION

A summary of environmental and economic comparisons for various energy sources is provided in Table 3. As shown on the table, several energy sources release minute amounts of radioactive materials to the environment. The releases from nuclear power plants are known, well documented and negligible when compared with our natural radiation environment. Recent reports indicate releases from coal fired plants

* This \$80 billion saving does not exist if pollution control equipment is installed on all coal plants.

of equivalent electrical capacity, where trace amounts of uranium, radium thorium, etc., are present, may be higher than radioactivity released from pressurized water reactors, but less than that released from boiling water reactors. The same appears to be true for some geothermal locations where radioactive materials are being released from the bowels of the earth.

RADIATION

In sufficiently large doses, radiation is always a potential hazard because of the opportunity to trigger cancers. Although humans are continually bathed in radiation from cosmic rays and the environment, man-made sources may provide a portion of the total dose. Perhaps 2% of all cancer deaths in the United States around the turn of the century may be radiation induced, assuming no improvements in diagnosis or cures. Of this number, twice as many will be from natural radiation than from medical x-rays, and 500 times as many will be from natural radiation than from reactor, coal or geothermal radiation.

An interesting phenomenon currently being evaluated is the correlation between the natural radioactivity present in cigarettes and the incidence of upper bronchial carcinomas. Another correlation exists between smoking and uranium miners. Miners who do not smoke have lung cancer rates slightly higher than population averages, but those who smoke experience some type of synergistic effect resulting in dramatic increase in the probability of contracting lung cancer.

Another recent report sought to correlate cancer rates with altitude of domicile. Those living at higher elevations are exposed to greater doses of cosmic radiation and should indicate a greater incidence of cancer. The results showed just the opposite. Suspecting an anomaly, investigators sought to determine if pollution might have biased the findings. The study was repeated using regions with above normal pollution levels and increasing altitudes. Again the results showed a decrease in cancers with an increase in altitude. Does this imply that radiation may be healthful? The author chooses to let the reader decide. Considering all forms of premature deaths and all possible causes, the general public is much more likely to expire as the result of burning coal and oil than from natural gas or nuclear fuels.

ACCIDENTS AND SAFETY

Accident situations have been evaluated for nuclear and fossil fueled plants and comparative assessments have been reported in the literature. A catastrophic nuclear accident appears to have the same probability as an oil plant disaster. The probability of a serious coal plant accident is considerably less, but the tradeoff lies in the poor safety record in the mines and air pollution. The principal danger from nuclear plants is an accident, while the dangers from coal are mining, transportation and routine emissions from the plant. Table 4 summarizes nonaccident coal and nuclear deaths.

TABLE 4. ESTIMATE OF COAL AND NUCLEAR DEATHS
TO GENERATE A 1 YEAR SUPPLY OF
ELECTRICITY

<u>COAL</u>	
MINING	200
TRANSPORTATION	100
BLACK LUNG	1,000*
RESPIRATORY (PUBLIC)	4,000

<u>URANIUM</u>	
MINING	2
LUNG CANCER (MINERS)	20

* One billion \$ paid yearly in compensation
to miners with black lung disease.

The safety record for nuclear plants is manifested in system redundancy and a "defense in depth" concept which attempts to mitigate any serious accident before it occurs. The record to date speaks for itself. Eight radiation deaths have occurred to occupational personnel associated with atomic energy and no deaths or injuries amongst the general public. Table 5 summarizes the occupational deaths attributed to radiation accidents. None have been associated with commercial power plants.

TABLE 5. OCCUPATIONAL DEATHS FROM NUCLEAR RESEARCH

1940's	Los Alamos Laboratory	2
1950's & 1960's	Los Alamos	1
	Rhode Island	1
	SL1 Reactor, Idaho	3
	Falls, Idaho	1
	Yugoslavia	1
1970's	None	0
TOTAL		8

From a different perspective, consider Table 6., the approximate number of deaths per year to the general public from various natural and man-made events.

TABLE 6. DEATHS PER YEAR TO GENERAL PUBLIC

Cancer	450,000
Automobile	45,000
Falls	18,000
Electrocution	1,000
Commercial airplanes	300*
Lightning	100
Venomous bites and stings	50**
Nuclear accidents	0

* This includes about 20 who were killed by falling aircraft.

** Arizona records show no recorded snake-bite death since 1972.

Based on historical records it is obvious that many fears about accidents are psychological. For example, many dread to fly despite statistics which show commercial aviation is many times safer than other modes of transportation. Flying hazards were recognized early and safety has been stressed. Sometimes, however, complacency or need for safety is not recognized and disaster strikes. "On January 15, 1919 an incredible 15 foot wave of molasses killed 21 people and demolished a two block area of Boston immediately after the rivets began to pop from a tank holding 2.2 million gallons of the sticky goo..." In an absolute sense, there have been more people killed from a tidal wave of molasses than the peaceful uses of atomic energy. Based on hindsight, those in the molasses business probably consider this accident to be an unexpected catastrophe. Not only were the number of deaths

deplorable, but the clean up must have been noteworthy. In order to evaluate the seriousness of an occurrence consider Table 7, a list of hypothetical events and resulting casualties.

TABLE 7. ACCIDENTS AND CASUALTIES

<u>Event</u>	<u>Worst Case</u>	<u>Most Likely</u>
Folsom Dam Failure & Flooding Sacramento	260,000	250,000
Plane Crash into Hollywood Park on takeoff from Los Angeles International Airport	32,000	6,000
Chlorine Tank Rupture	20,000	10
Reactor Meltdown	3,200	0

It is useless to describe events without mentioning the probability of occurrence. From historical records probabilities can be predicted for the various natural or man-made accidents. Table 8 summarizes a few of the accidents where fatalities exceed 1000.

TABLE 8. ACCIDENT PROBABILITY WHERE DEATHS EXCEED 1,000

<u>Event</u>	<u>1000+ Fatalities</u>	
Hurricane	1 in	25 years
Earthquake	1 in	50 years*
Dam Failure	1 in	100 years
Explosion	1 in	120 years
Fire	1 in	200 years
Toxic Gas	1 in	1,000 years
Airplane Crash	1 in	2,000 years
Meteorite	1 in	1,000,000 years
100 Reactors (1980)	1 in	1,000,000 years

* If 1976 earthquakes included, probability is greater. In February, 22,000 died in Guatemala. In July-August many died in the Philippines and mainland China quakes.

INSURANCE

Companies operating facilities which may be responsible for serious accidents and large liability or property claims, such as those owning dams, airplanes, or refineries generally do not insure on a plant-by-plant basis. A broad form public liability insurance is carried as a method of transferring a portion of the public liability exposure. Most large companies buy \$10-\$30 million policies, although larger coverages have been written. Table 9 lists several organizations with large coverages.

TABLE 9. ORGANIZATIONS WITH LARGE INSURANCE POLICIES

State of California:	\$50 million (dams, aircraft)
City of San Francisco:	\$50 million (dams)
University of California:	\$50 million (medical facilities, athletic stadiums)
Standard Oil of California:	\$100 million (refineries, storage tanks for oil and gasoline)
Pacific Southwest Airlines:	\$100 million
Pan American World Airways:	\$200-\$250 million
Los Angeles Department of Water and Power:	\$100 million

Because no one company will provide such vast coverage, each of these policies involves a large number of insurance companies. Dispersion of policies results from the insurance industry's preference for distributed risk. An insurance company would rather sell a large number of small policies than a few large policies and prevent bankruptcy as a result of one major accident.

Utilities purchase insurance commensurate with the energy source and the assets of the organization. For fossil and hydro plants, the insurance is obtained in a conventional manner with limits generally based on the size of the organization. Some obtain large deductibles and assume the initial risks. Nuclear power plant insurance, however, differs from conventional forms in several respects. The insurance is no fault and requires no action to prove negligence or establish blame. By common law and the Price Anderson legislation, the licensed utility must subscribe to the insurance available from private insurance pools, currently \$125 million, and then must agree to indemnify by the federal government up to the limitation of liability which has been established at \$560 million. In the event damages ever exceed the limit of liability, the government would probably enact emergency disaster-relief legislation. During the past 20 years about \$400,000 in claims have been filed. However, none of these claims involve the nuclear portion of commercial power plants. Because of the perfect safety record of commercial nuclear reactors, the private insurance pools are rebating about 70% of the fees. The federal government does not rebate indemnity fees and has collected over \$20 million from utilities with nuclear reactors. In order to determine if the current limits of liability are adequate, Table 10 compares the accident damage to the public from nuclear and various other accidents.

TABLE 10. ACCIDENT COSTS

(\$ millions)

Automobiles	5,000	each year
Hurricane Agnes	3,000	1972
San Francisco Earthquake	2,000	future
Folsom Dam Failure	570	future
Los Angeles Earthquake	480	1971
Fires	10	3 each year
Nuclear Reactors	10	Once in 600 yrs
	1	Once in 200 yrs

Since nuclear no-fault insurance is required by law and paid for by the utilities, homeowner policies contain an exclusion for nuclear accidents. Table 11 summarizes the exclusions that are contained in most homeowner policies.

TABLE 11. HOMEOWNER INSURANCE EXCLUSIONS

<u>Maintenance Risks</u>	<u>Man-made Hazards</u>	<u>Natural Hazards</u>
Settling	War	Earthquakes
Wear and tear	Smog	Landslides
Vermin	Radiation	Floods*
Sewer backup		

*Including dam failures caused by "Acts of God".

Some of the natural hazard exclusions may be insured by special coverage, the rates are often high, and some may be available through the federal government.

CONCLUSION

Energy sources and options must be understood and viewed in perspective by laymen and legislators as well as engineers and scientists. It takes little effort to criticize, list problems or verbalize on methods to achieve utopia--"the great society." Moreover, we have no moral or intellectual justification for becoming obsessed with hypothetical hazards, speculation and "what if" scenarios when factual information is available to document an opinion. Man's best insurance for a peaceful, productive and rewarding future rests in the assurance that individual and collective

decisions made today provide the most advantageous compromise between assets and liabilities. The challenges of establishing an energy policy with realistic short and long range must be recognized and addressed by all.

ACKNOWLEDGMENTS

The author wishes to recognize and express sincere appreciation to the individuals who reviewed the article and provided meaningful suggestions for improvement.

Dr. Gordon M. Dunning
Commissioner
Arizona Atomic Energy Commission

Mr. Earle Maynard, President
Earle Maynard & Company
Insurance Brokers
San Francisco, California

Mr. Garvis Pollard
Nuclear Technology Specialist
Arizona Atomic Energy Commission

Dr. Claude Poncelet
Scientific Advisor
Energy Action Office
Westinghouse Power Systems Company
Pittsburgh, Pennsylvania

Mr. Sidney Wilcox
Professor of Engineering Communications
Arizona State University

BIBLIOGRAPHY

1. Adams, J. and Lowder, W. (Eds.). The Natural Radiation Environment. Chicago: University of Chicago Press, 1964. Proceedings of an International Symposium held at Rice University, Houston, Texas.
2. American Nuclear Society, Nuclear Power and the Environment: Questions and Answers. Hinsdale, Illinois, 1976.
3. Beckman, P. The Health Hazards of Not Going Nuclear Power. Golden, Colorado: Golem Press, 1976.
4. Bertine, K. K. and Goldberg, E. D., "Fossil Fuel Combustion and the Major Sedimentary Cycle," Science, 173, 233-235 (1971).
5. Comar, C. L. and Sagan, L. A., "Health Effects of Energy Production and Conversion," Annual Review of Energy, 1, 581-600 (1976).
6. Cuffe, S. T. and Gerstle, R. W., "Emissions from Coal-Fired Power Plants: A Comprehensive Study," U. S. Department of Health, Education and Welfare, Public Health Service, Durham, North Carolina, 1967.
7. Eisenbud, M., Environmental Radioactivity. New York: Academic Press, 1973.
8. Hans, J. M., Jr., and Sell, T. C., Evacuation Risks - An Evaluation. U. S. Environmental Protection Agency, EPA-520/6-74-002, National Environmental Research Center, Las Vegas, Nevada, 1974.
9. Hull, A. P., "Average Effluent Releases from Nuclear Power Reactors, Compared with those from Fossil Fuel Plants, in Terms of Currently Applicable Environmental Standards," BNL-18823, Brookhaven National Laboratory, Upton, New York, September, 1973.
10. "Insurance Experience Indicates that Nuclear is One of the Safest Industries on Earth," Forbes, p. 59, June, 1976.
11. Joensuu, O. I., "Fossil Fuel as a Source of Mercury Pollution," Science, 172, 1027-1028 (1971).
12. Lapp, R. E., Nader's Nuclear Issues, Facts Systems: Greenwich Conn., 1975.
13. Lapp, R. E., The Nuclear Controversy. Facts Systems: Greenwich Conn., 1975.
14. Loveland, W. D., Spinrad, B. I. and Wang, C. H., (Eds.). Conference on Magnitude and Deployment Schedule of Energy Resources, Office of Energy Research and Development, Oregon State University, Corvallis, Oregon, September, 1975.

15. Maynard, E. V., "Insurance, Price-Anderson, and the Nuclear Power Controversy," The Broker, pp. 12-14, April, 1976.
16. Poncelet, C. G., "Energy Economics," presented at the Energy in Perspective Conference for Educators, Arizona State University, June, 1976. Copies available from author at Energy Action Office, Power Systems Company, Westinghouse Electric Corporation, Box 355, Pittsburgh, Pennsylvania.
17. Siri, W. E., Higgins, G. H., et. al. Impacts of Alternative Electricity Supply Systems for California and Analysis of Supply Demand of Electricity for the 12 Western States, 1973-1990, Western Interstate Nuclear Board, Lakewood, Colorado, May, 1976.
18. U. S. Atomic Energy Commission, The Safety of Nuclear Power Reactors and Related Facilities, Final Draft, July, 1973.
19. U. S. Energy Research and Development Administration. A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, Vol. 1, The Plan, ERDA 76-1, Superintendent of Documents, U. S. Government Printing Office, Washington, D.C., 1976.
20. U. S. Energy Research and Development Administration, The Environmental Impact of Electrical Power Generation: Nuclear and Fossil, ERDA-69, Pennsylvania Department of Education, Superintendent of Documents, Government Printing Office, Washington, D.C., 1975.
21. U. S. Nuclear Regulatory Commission, Reactor Safety Study - An Assessment of Accident Risks in U. S. Commercial Power Plants, Wash-1400 (NUREG-75/014), NTIC, Springfield, Virginia, 1975.
22. Wang, C. H., Nachtwey, D. S. and Loveland, W., Electric Power Generation: Comparative Risks and Benefits. Institute of Nuclear Science and Engineering, Oregon State University, Corvallis, Oregon, 1973.
23. Whipple, C., "Insurance of Nuclear Power Plants," unpublished.

FUSION REACTORS AND THEIR FUEL CYCLE: A PRIMER**

By
DR. R. G. WYMER

Associate Director
Chemical Technology Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37830

*Operated for U.S. ERDA by Union Carbide Corporation

**Research sponsored by the U.S. Energy Research and Development
Administration under contract with the Union Carbide Corporation.

FUSION REACTORS AND THEIR FUEL CYCLE: A PRIMER

Introduction

The projected growth in the per capita use of energy in the United States and elsewhere, if realized, would necessitate commensurate growth in energy producing capacity. More and more the broadly inclusive word "energy" is interpreted to mean electrical energy, and the energy production capability being added is to a large extent in that form.

The newer methods of electrical energy production in use (fission reactors) or proposed (fusion reactors, the subject of this essay) differ from the older methods in their potential for long-term energy production, and in their social, economic and environmental implications. However, in their current conception they are like the most widely used older methods in that they are basically heat machines, held in the unrelenting grip of the second law of thermodynamics.

The primary impetus for developing fusion reactors as a major source of energy production lies in their assumed potential to produce an effectively limitless amount of energy in an economically, and otherwise, acceptable way. By way of comparison, solar energy is also effectively limitless, but the known ways of collecting and storing it are not generally considered to be economically feasible on the scale and at the rate called for by the projected energy growth.

Despite the somewhat misleading claims which are sometimes made that energy from fusion would be free of the environmental problems of

energy from fission - most notably free from the radioactive by-products-, and the overly optimistic statements as to the amount of time it will take to bring practical, economical fusion-produced energy onto the scene on a significant scale, it is apparent that no element of natural law rules out the possibility of producing energy by fusion reactions.

In this essay a very limited and elementary view of fusion has been adopted, first because it is easier to understand the nature of the processes by which energy may be produced by fusion reactors if the discussion is kept simple, and second, because being acquainted primarily with the problems and development programs related to fusion reactor fuel recycle, rather than with the machines themselves.

That fusion reactions truly can produce massive amounts of energy has been abundantly demonstrated on earth by explosion of the so-called "hydrogen bombs" (first achieved in 1952); fusion is also the source of the sun's energy production. The problem being attacked is that of finding a way to control the release of energy from the fusion reactions. This problem is analogous to the problem that was solved in controlling the energy released by fission reactions in the atomic bomb, leading to the fission reactors as practical energy producing machines. There is at present a strong tide running in favor of a large increase in Federal support of fusion reactor development in the United States, apparently motivated by the belief the fusion reactors will help solve the Nation's long-term energy and related problems in a timely way. It seems prudent to observe that the problems associated with developing practical fusion reactors are formidable--in fact, awesome. In what follows it may become apparent that one must be uncommonly optimistic to believe that

practical fusion energy is "just around the corner," or is quite the near-term panacea some purport it to be.

Notwithstanding the above comments about excessive optimism, it should be noted that major development programs in fusion are underway in USSR (37.1), US (15.8), Germany (13.0), Japan (9.3), France (7.2), and UK (4.2). The numbers in parentheses refer to the percent of the total world effort the various nations have.

Fundamental Phenomena and Resources

When nuclear reactions occur with a mass decrement, that net mass loss appears as energy released, and the reactions are "favorable", i.e., they may be expected to take place. However, just because reactions can take place, it is not to be expected that they will take place. This is the crux of the problem in fusion reactions. It finds an analog in the fields of chemical thermodynamics and chemical kinetics. Every student of chemistry knows that while the thermodynamics of a reaction governs its possibility and degree, the kinetics govern its rate, and so, in a practical sense, determines whether it will occur. The concept of "activation energy" has been developed to aid in understanding the observations of chemical kinetics. Activation energy is that energy required (apart from the thermodynamic energy) to put reactants in a state that permits them to go to products. In the case of fusion reactions the analogous energy is that required to overcome the electrostatic repulsion of the charged nuclei and thus to permit their fusion.

When fission reactions occur with the heavy elements such as ^{235}U , ^{239}Pu , and ^{233}U , two, and very occasionally three, fission "fragments" and two or three neutrons are released. The sum of the masses of these

new fragments (chemical elements of lower atomic number than the reacting atom) and of the neutrons is less than the sum of the masses of the heavy element and the neutron that caused it to fission. The amount of energy released is related to the mass loss by the familiar Einstein equation $E = mc^2$, where c is the speed of light, units are in the cgs system, and m is the mass decrement. Thus, the reaction is favored by producing elements of lower atomic number than the original heavy element. Conversely, when fusion reactions occur, light elements such as isotopes of hydrogen, lithium or helium react in pairs to produce elements which individually have higher atomic number or mass or both than the reacting atoms; but there is a net mass loss in this case too, and it also appears as energy.

The fusion reactions of current greatest interest in fusion reactor studies are given in Table 1. The "breeding" reactions involving lithium and beryllium are also given. These reactions are those required to permit production of energy, and at the same time generate more fuel than is consumed, thus allowing more fusion reactors to be built. This is, in a sense, a breeding phenomenon. It will be seen that the primary reactant materials needed are deuterium, tritium and lithium. Beryllium has been included because it has potential use as a neutron "multiplier." However, its limited supply may limit its use. A variety of other reactions might also be listed, but the ones shown are the principal ones.

Since fusion reactors are being considered seriously as major long term energy sources, it is well to consider the magnitude of the supply of the reactants. Seawater contains 33 grams of deuterium per cubic meter, giving a world supply of 5×10^{19} grams. (One gram of deuterium

TABLE 1
SELECTED FUEL CYCLE REACTIONS

	Reactants*		Products (Mev)		"Activation" Energy (Kev)
(1)	D-T	→	${}^4\text{He}$ (3.5) + n (14.1)		6
(2)	D-D	→	${}^3\text{He}$ (0.82) + n (2.45) T (1.0) + p (3.02)	}	40
(3)	D- ${}^3\text{He}$	→	${}^4\text{He}$ (3.6) + p (14.7)		50
(4)	${}^7\text{Li}$ - fast n	→	T + ${}^4\text{He}$ + slow n**		--
(5)	${}^6\text{Li}$ - slow n	→	T (2.06) + ${}^4\text{He}$ (2.74)		--
(6)	${}^7\text{Li}$ - fast n	→	${}^6\text{Li}$ + 2 n		--
(7)	${}^9\text{Be}$ - fast n	→	${}^8\text{B}$ + 2 n $\downarrow \beta^+$ $2 {}^4\text{He}$ $t_{1/2} = 0.46 \text{ sec}$		--

*It is to be understood that in reactions 1 through 3 the reactants and products typically will be completely ionized.

**This reaction is endoergic, requiring 2.5 Mev.

is the energy equivalent of 12,000 kg of coal.) Tritium, which is produced naturally by bombardment of nitrogen and oxygen by cosmic rays, and decays with a half-life of 12.3 years, has a global inventory of perhaps 2 to 10 kg. Lithium, which as found in nature is comprised of 7.42% ^6Li and 92.58% ^7Li , has known and inferred reserves in the U.S. of about 6×10^{12} grams, 80% of which is in the Nevada and California heavy brines. (Burned in D-T fusion reactors at about 2.5×10^4 kwht* per gram this much lithium yields 1.5×10^{17} kwht.) Beryllium is found in nature 100% as the isotope ^9Be . The estimated reserves are 80,000 tons. From this it is clear that a fusion reactor economy must rely on deuterium and lithium as raw materials and that deuterium and lithium supplies are adequate to meet projected energy needs.** Although tritium may ultimately be produced as shown in equations 4 and 5 of Table 1, it must come from sources already in existence for use in the period of the early 1980s through 2000. The BRDA reactors at Savannah River may well be one such source. Although tritium is also produced in power reactors, it is unlikely that such reactors will be an adequate source of tritium (it would have to be obtained through the intermediate steps of fuel reprocessing and tritium isolation).

Fusion reactions such as those shown in Table 1, equations 1 through 3, take place when the gaseous ions collide with each other with enough energy to overcome the electrostatic repulsion of their nuclei. The energy required for this to take place is so great that it also prac-

* "kwht" stands for kilowatt-hours thermal, which means kilowatt-hours of heat energy.

** For a simplified discussion of energy needs and resources in the context of the capability of various methods of energy production to meet future world needs see "The Prospects of Fusion Power," Scientific American, Vol. 224, No. 2, pp. 50-64 (Feb. 1971).

tically completely ionizes the "plasma." (A collection of partially or fully ionized gaseous atoms is called a plasma. A new scientific discipline called plasma physics is being developed to deal with the practical and theoretical problems of fusion experiments and reactors. The properties of plasmas are so different from those of solids, liquids and gases that they are sometimes called the fourth state of matter to stress their uniqueness). The temperature corresponding to the energy required for fusion is of the order of 100 million degrees (at temperatures this high it is not particularly instructive to indicate what temperature scale is used). From this it is obvious that no material can contain the plasma. However, because the plasma is made of charged particles (essentially atomic nuclei and electrons) it can be affected, and in principle contained, by magnetic (or electric) fields. This is, in fact, the principal containment approach being followed. The plasma is confined by magnetic fields shaped so as to keep the plasma away from the wall of the plasma container. (About \$105 million may be spent by the Energy Research and Development Administration (ERDA) in FY 1976 on this approach). There is, however, an alternate approach to confinement (called inertial confinement) being studied, as will be discussed later under the heading of "laser-type" fusion reactors. (About \$60 million may be spent by ERDA in FY 1976 on this approach, largely in laser research by the military).

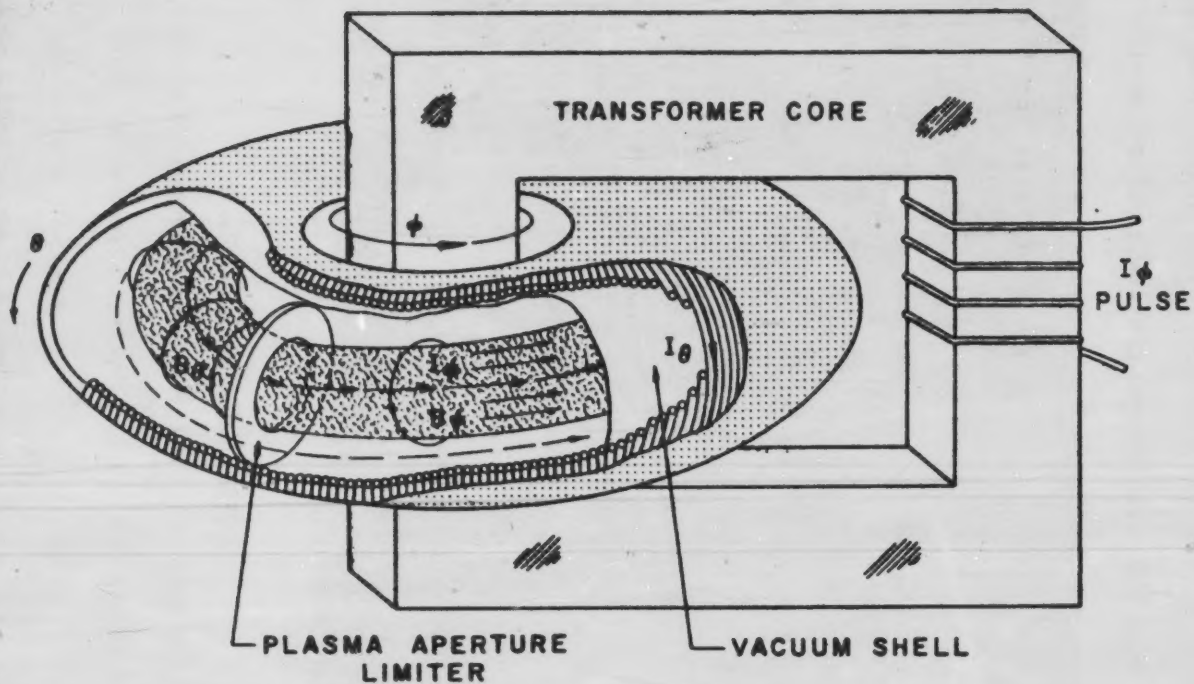
In addition to the requirement that charged particles have sufficient energy (that is, that the "temperature" be high enough) to fuse, there must also be a sufficiently high concentration of ions to permit a practical reaction rate. Depending on reaction details, ion densities in the range of 10^{10} to 10^{14} ions per cubic centimeter (about one

millionth of an atmosphere), and confinement times of 0.01 to 1 second are required for a useful fraction of the fuel to fuse. Because both plasma density and reaction time are important and are interrelated, a useful parameter called the Lawson criterion has come into use. This criterion says that the time-concentration product should exceed $\sim 10^{14}$ ion-sec per cubic centimeter. [As an aside it may be noted that a typical (5000-Mwt) fusion device might contain at any time in its reacting plasma only one or two grams of tritium or deuterium⁷.

There are two basically different approaches to magnetic confinement of plasmas: (1) closed systems and (2) open systems. In closed systems the magnetic fields are arranged so as to cause the plasma particles to follow closed paths in a repetitive manner. In open systems the magnetic fields cause the plasma particles to follow paths which are often more or less linear, and in any event, are not intentionally closed. Thus, in closed systems the paths do not end (at least in the main), while in open systems the paths do move to the ends of the confinement system. Open systems thus are subject to "end losses" of the plasma. This distinction is made clear in Figs. 1 through 3 in what follows.

Tokamak (Closed System)

Figure 1 is a highly simplified schematic representation of a closed plasma confinement device called a Tokamak. This is a Russian invention, and is the most promising magnetic confinement scheme now under study. Several major experiments based on this scheme are underway in the U. S., and more are planned. Rather extensive considerations of the total requirements for producing a fusion-reactor-energy economy have been made using Tokamaks as representative of a class of fusion



THE TOKAMAK PLASMA CONFINEMENT SCHEME

Figure 1

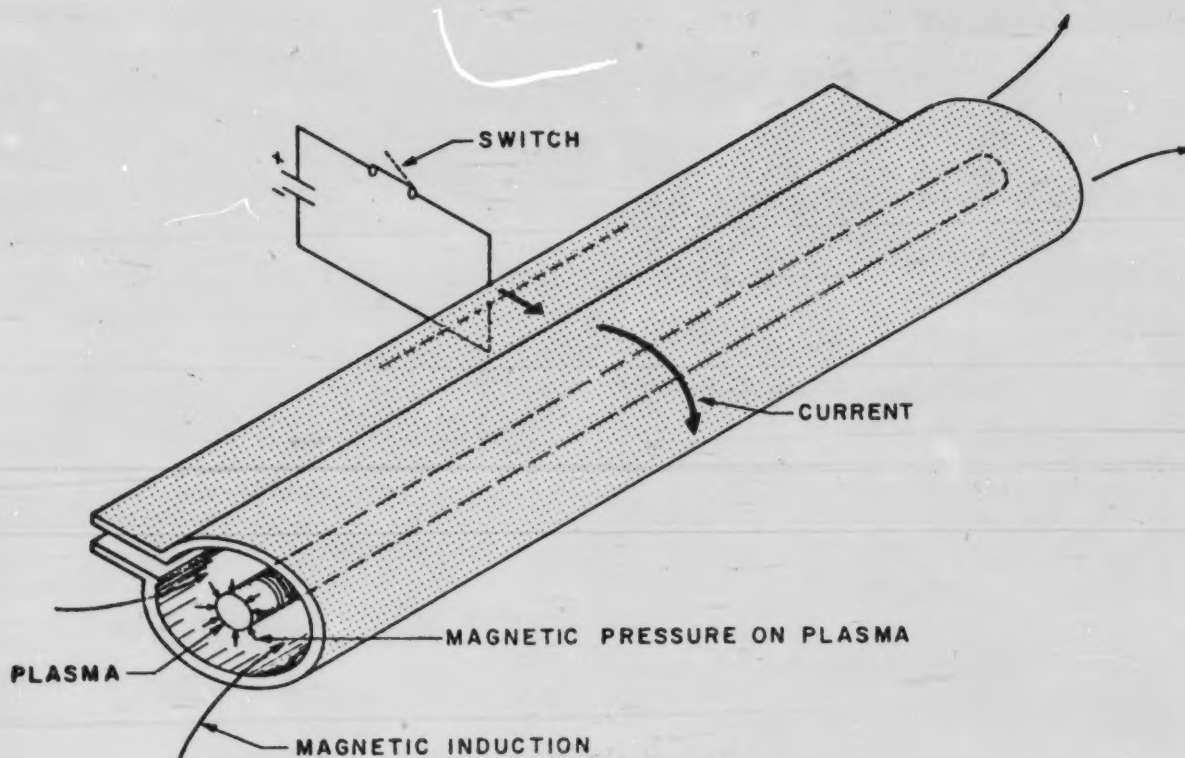
reactors. Some of these considerations and their implications will be given in later sections of this essay.

In the Tokamak scheme the current, I_0 , in the windings around the "doughnut" produces an azimuthal magnetic field, B_θ . Charged particles are thus constrained to occupy the torus, since there is no way for them to escape without crossing magnetic field lines. Beyond this, a pulse I_ϕ is applied to what amounts to the primary winding of a transformer core. The plasma, being composed of charged particles, reacts as do electrons in the secondary winding of any transformer--it moves, producing a current I_ϕ in the torus. This plasma movement is not ideally smooth, but is turbulent, leading to plasma heating. Further, the current I_ϕ produces a magnetic field of its own, designated B_z in Fig. 1. This field, combined with the field B_θ , produces a net field which so far shows promise of giving adequate plasma confinement. Because it is necessary to shut down the fusion reaction periodically to remove reaction products and other impurities which accumulate, the Tokamak is essentially a pulsed device, pulsing at a rate of about 5000 pulses per year, or about 1.6 hours per cycle in large reactors. The plasma heating resulting from the transformer action is not enough to produce the ion energy needed for fusion, so additional energy is introduced through the use of neutral particle injection. Deuterons or tritons of 500 kev and 15 MW may be injected tangent to the magnetic axis. The energy and power of the neutral particle beam are specific to a particular Tokamak design. The values given are for a 5000 Mwt reactor having properties listed in Table 3 in the discussion on Engineering Considerations.

Theta-Pinch (Open/Closed System)

Figure 2 is a schematic representation of a theta-pinch system as an open plasma confinement device. This device is called a theta-pinch device, so named because the current giving rise to the confining magnetic field goes around the plasma in a surface defined by the coordinate θ (theta), as it is customarily defined in cylindrical and spherical coordinates. In large-scale concepts of this device a capacitor bank discharges through the (effectively) single-turn coil. This action implodes radially the initially "cool" plasma, forming a hot one. Further compression of the hot plasma to ion concentrations required for fusion reactions is accomplished by relatively slow adiabatic compression via a magnetic field. This sequence of events is shown schematically in Fig. 3. The whole "burning" and fuel recycle operation takes 3 seconds. In actual tests, plasma density and temperature are respectably high, but containment times are far too short ($\sim 10^{-5}$ second); further, the plasma squirts out the ends of the device. Of course building a longer device reduces the relative effect of end losses. The ultimate in a long device is one having a closed path, that is, a torus. Thus, the theta-pinch devices have adopted a toroidal configuration in their current conception, just as the Tokamaks. The more advanced concepts are "staged" devices.

In staged devices the energy input to the single turn coil is replaced by one energy source for the implosion heating step, and another for the adiabatic compression step. The implosion heating field is produced in a few microseconds by a low-energy, high-voltage discharge through a thin coil cooled by liquid metal. The adiabatic compression field is produced by a more slowly rising high-energy, low-



PULSED PLASMA HEATING AND CONFINEMENT SCHEME
" θ PINCH"

Fig. 2

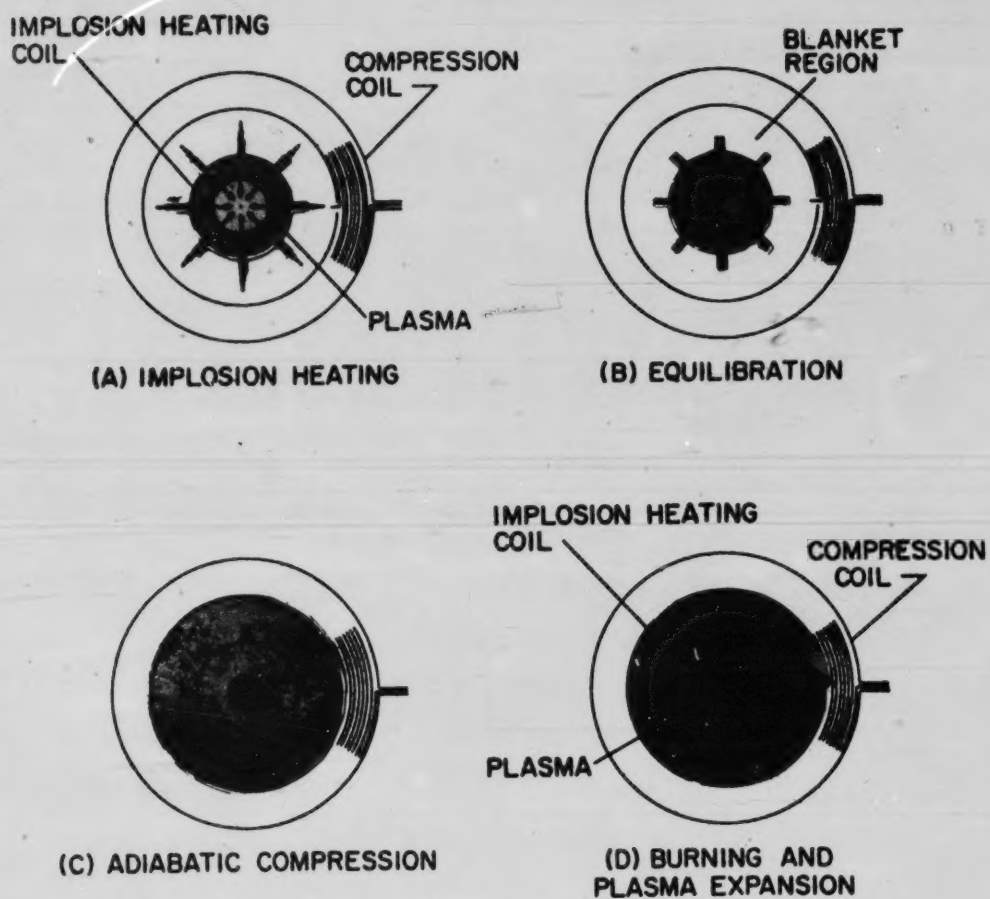


Fig. 3 Plasma Heating and Burning Sequence in a Theta-Pinch Reactor

voltage discharge through a many-turn compression coil for tens of milliseconds. This coil is located outside a neutron-moderating blanket, and is cooled with gaseous helium.

In one reference design of a theta-pinch reactor the torus has a minor radius of 500 cm and a major radius of 56 meters. A 40 cm blanket of lithium, beryllium and graphite surrounds the plasma chamber. The implosion heating coil is located outside the blanket. The (40 cm-thick) adiabatic compression coil surrounds the implosion coil. The device is fueled with a 50:50 mixture of deuterium and tritium. The thermal power produced by this reference theta pinch reactor (RTPR) concept is 3600 MWt, which is based on a total cycle time of 10 seconds per pulse. The resulting power loading on the first wall (the wall adjacent to the plasma) is about 2.0 MW/m^2 . This loading is about the same as the first wall loading for the reference Tokamak described later. Figure 4 shows one of 176 modules which make up the RTPR. Each module has an outside diameter of 3 meters, an overall length of 2 meters, and weighs about 70 tonnes. The following listings give some of the operating information for the RTPR.

Fuel Requirements

^2H	0.97 kg/day
^3H	1.46 kg/day
Li	3.36 kg/day

Operating Cycle

Plasma preparation time	30 msec
Plasma burn time	70 msec
Plasma quench time	30 msec
Plasma gas-blanket cooling time	1 sec
Burning and fuel recycle time	3 sec

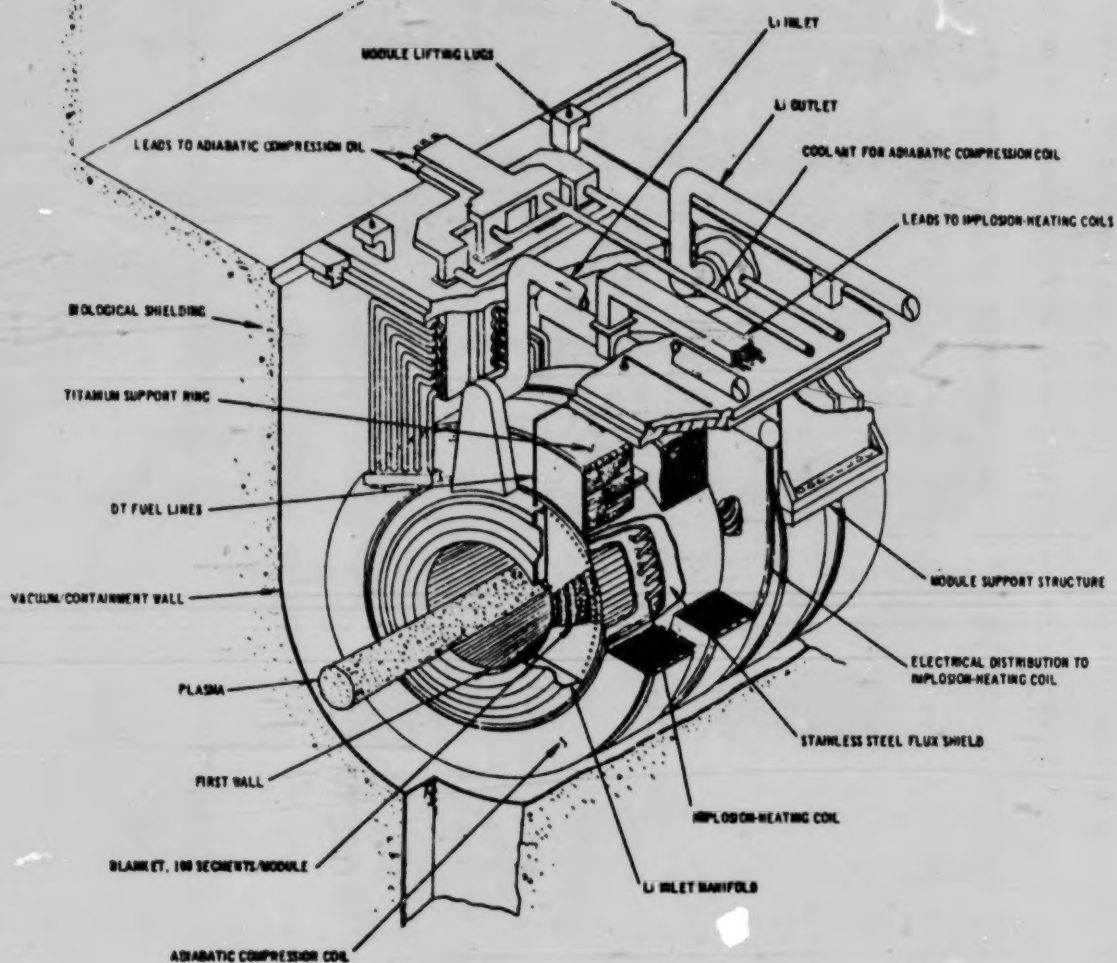


Fig. 4 Cutaway View of a Two-Meter-Long Reference Theta-Pinch Reactor Module.

Magnetic Mirror (Open System)

Figure 5 is a schematic representation of an open plasma confinement device called a magnetic mirror. In the magnetic mirror scheme a current moves as shown in the two parallel coils at opposite ends of the plasma, producing a magnetic field that constrains the plasma along the axis of the coils. The plasma may be heated by radiofrequency heating of the tritium and deuterium, or by particle injection. If the magnetic field is large enough, the magnetic lines of force are so close as they pass through the coils that there is too little energy in the charged particles in the component of velocity along the axis of the coils to permit them to get through the coils and escape. Thus, they are effectively "reflected" back into the region between the magnets by the magnetic "mirrors". In practice, the particles do leak through the coils because of nonidealities in the system. Mirror schemes also do not appear to have the capability of heating the plasma enough for practical fusion, and some sort of energetic particle injection system appears to be necessary to attain the requisite "temperature", just as is required in the Tokamak. It may be noted that the leaks of plasma out the ends of the device may be turned into an asset. If reaction 3 of Table 1 ($D + {}^3\text{He} \rightarrow {}^4\text{He} + p$) were used in mirror devices, nearly all the particles would be charged, and as these "squirted" out the end, the electrons and ions in the plasma could be separated, allowing their subsequent recombination in an electrostatic direct energy conversion system. It should, however, be noted that a 50 Kev "activation" energy is required for the ($D - {}^3\text{He}$) reaction, in contrast to the 6 Kev needed for the D-T reaction. Some concepts of the mirror device involve a toroidal configuration; others involve a near-spherical configuration.

Laser-Type

Figure 6 shows schematically a wholly different concept for producing fusion reactions. This idea does not rely on a plasma of high energy, high ion concentration and long lifetime to produce useful fusion reactions. Instead, "pellets" of solid deuterium and tritium are introduced into an evacuated system where they are heated by a very high energy density pulse of radiant energy. The result is a virtually instantaneous vaporization of the outer layer of the pellet, with a concomitant reactive inward pressure on the remainder of the pellet. This implosion produces sufficient pressure to cause fusion of the residual deuterium and tritium. Because the times are so short that fusion occurs before the plasma can "explode", this type of plasma confinement is sometimes called "inertial confinement." The figure shows this schematically, as well as a concept of how such a laser fusion reactor might look. As in the case of the magnetically confined plasma devices, the laser-type reactor must have a lithium-containing blanket to produce tritium. So far, much attention has been paid to the severe problems related to developing the lasers. It is, for example, most difficult to get radiant energy of the intensity required through the various windows required without destroying the windows. Further, focusing the energy more or less uniformly on the pellets is a difficult requirement, and energy reflection from the pellet surface may be high. Current concepts compound this problem by requiring up to eight laser beams to strike a fuel pellet simultaneously. Finally, of course, preparing pellets of deuterium and tritium and getting them into the device are significant problems. Notwithstanding these problems, there are major

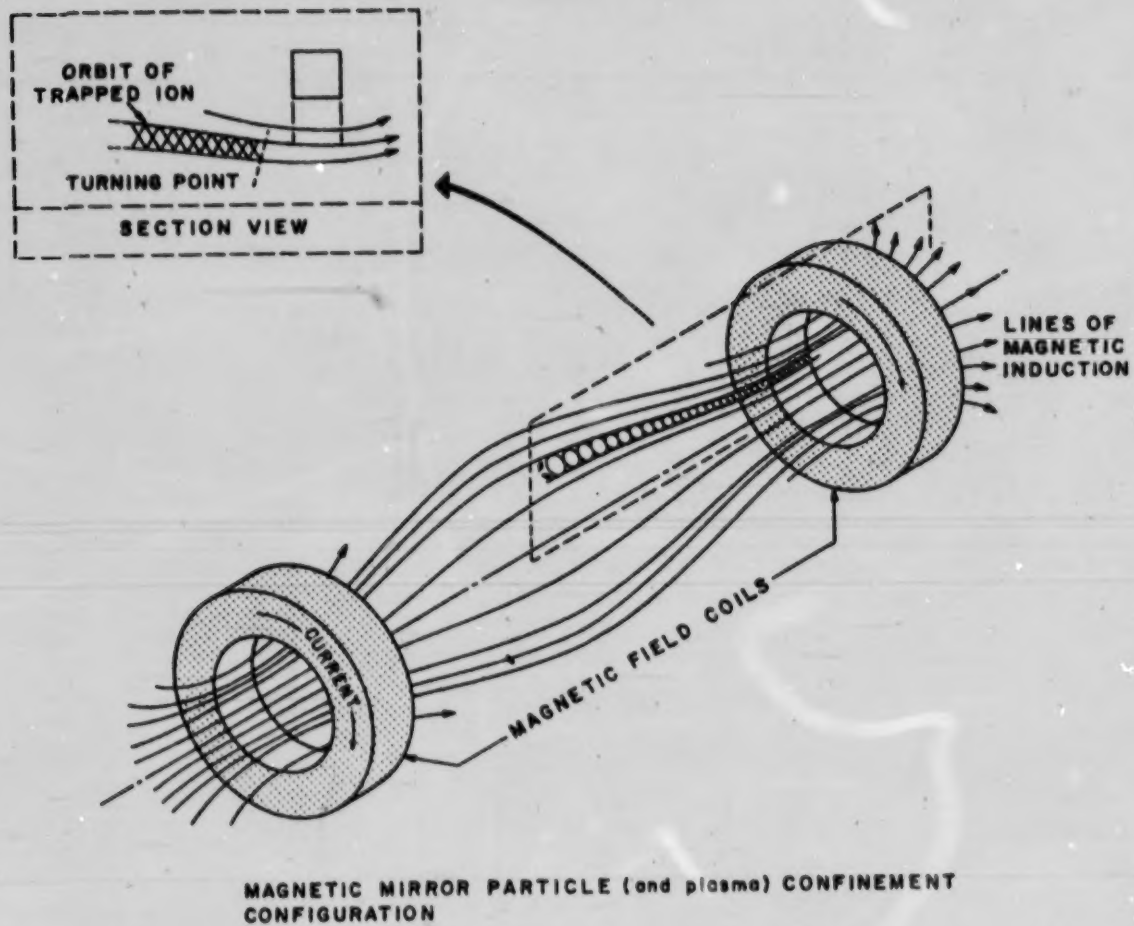
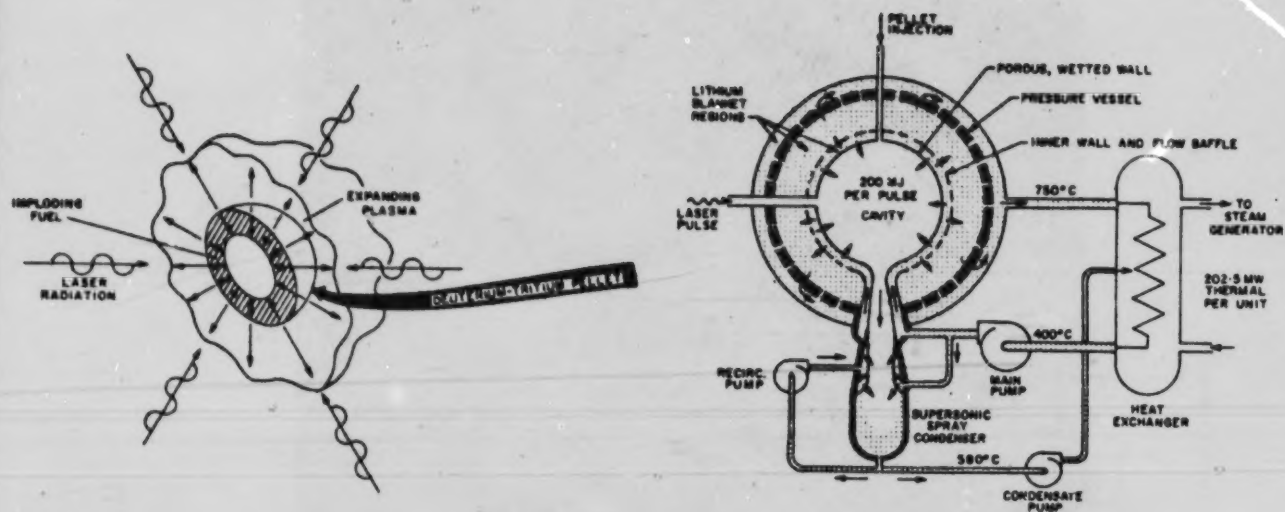


Fig. 5



LASER FUSION REACTOR

Fig. 6

efforts on this fusion concept in the U.S. and elsewhere, most notably in Russia. (It may be worth emphasizing that this type of fusion reactor may be getting support out of proportion to its promise because of the obvious military interest in developing the lasers).

Fuel Recycle

If fusion is to be a practical source of energy, then tritium must be produced in fusion reactors, and must be recovered for use in further fusion reactions. Further, since not nearly enough tritium occurs in nature to support fusion reactors as energy sources, more tritium must be produced in a reactor than it uses if additional reactors are to be built. Thus, fuel recycle is essential, and so is breeding.

The principal features of one approach to fusion reactor fuel recycle are shown in Figure 7. This figure also shows a method for producing electrical energy. From Table 1 it is apparent that most of the energy from the D-T reaction appears as kinetic energy of the neutrons produced. This energy is dissipated by collisions and capture of the neutrons in the lithium blanket, heating the lithium, and at the same time producing some tritium (plus He and neutrons) in the lithium. These tritium-producing (breeding) reactions and several related factors are shown in Table 2. The high breeding ratio (1.49) inventory (30 kg of tritium in a 5000-MWt magnetically confined fusion reactor system) lead to a very short doubling time.* (Doubling times in the range of two to three months have been estimated. These may

* "Doubling time" is the time required for a reactor to produce a sufficient excess of fuel to supply fuel for another reactor like itself.

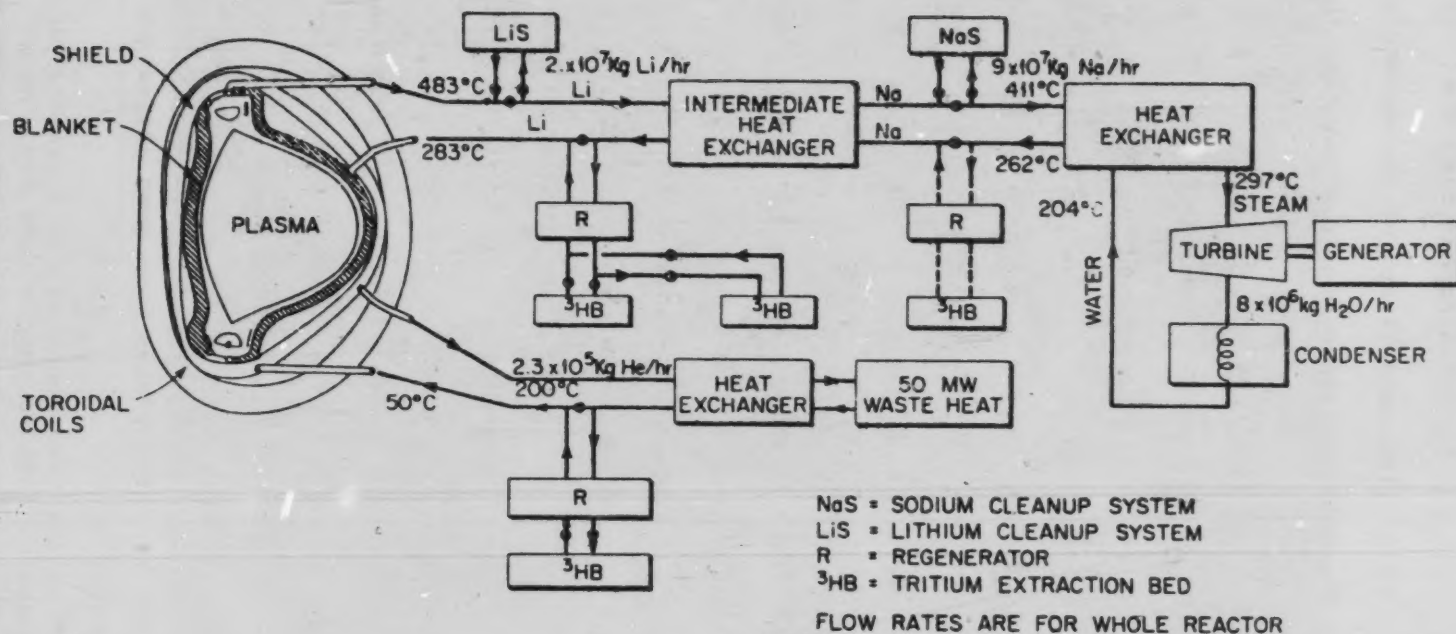


Fig. 7 Salient Features of Fuel Cycle and Electrical Energy Production

be contrasted to doubling times of 7 to 10 years for LMFBRs operating with as-yet-to-be-developed advanced fuel such as uranium-plutonium carbides).

TABLE 2
TRITIUM BREEDING

Lithium and deuterium are the raw materials consumed; tritium and deuterium are the reactants in the plasma.

Process: ${}^6\text{Li} (n, \alpha) {}^3\text{H}$
 ${}^7\text{Li} (n, \alpha n') {}^3\text{H}$

Blanket Design: Lithium also acts both as a blanket and as a coolant. Molten salts (F Li Be) are possible alternatives; however, Be is an essential part of any such salt.

Breeding Ratio: 1.49

Doubling Time: 2 - 3 months

Figure 7 shows that two tritium recycle systems are needed: one system--the major one--handles the tritium that is bred in the lithium blanket (~1 kg per day in a 5000-MWt reactor); the other system handles the tritium-hydrogen-deuterium-helium mixture from the plasma (a few grams of hydrogen per day are expected).

In the long term, the most promising systems for recovering tritium from the lithium blanket in which it is bred involve the use of lithium containment systems in which some of the metals are permeable to tritium. These metals must be resistant to "hydride" embrittlement. (Less than 10% of the total recycled lithium stream need be diverted to the tritium removal system). In the short term the more conservative approach of absorption with yttrium is assumed.

In Fig. 7 the tritium is shown being removed before and after it leaves the intermediate heat exchanger. An essential requirement is that the tritium be kept out of the steam cycle, because if it gets into the steam it cannot be assured that it can be kept out of the environment. It appears that only one part in 10^7 to 10^8 of the total plant tritium inventory (~ 30 kg ^3H) may be discharged if permissible discharge limits (assumed to be 10 curies/day) are to be met⁷.

The tritium recovery system could be a device resembling a tube and shell heat exchanger, with the lithium stream circulating inside the tubes, and the tritium permeating the tube walls into the shell, from which it is removed. For this system to work, the pressure of tritium in the shell must be less than the tritium pressure from the lithium which contains it in the tubes. Estimates of the allowable tritium pressure in the shell give values of 10^{-10} to 10^{-11} atmosphere.* At present, it appears that chemical "gettering" systems for tritium, e.g., yttrium (as shown in Fig. 7) may be useful to reach these low tritium pressures.

Coatings of low-permeability materials (such as oxides) may be required for the steam side of the water boiler surface to permit having reasonable (i.e., practically attainable) tritium pressures in the sodium (or other fluid) side. The subject of tritium permeation through various materials, e.g. metals and their oxides, is one that requires considerably more study.

*The maximum allowable tritium pressure was estimated from the relation $P_{T_2} = \left(\frac{R}{Ap/t} \right)^2$, where R is the maximum allowable tritium release rate to the steam system, p is permeability, A is the surface area of the heat exchanger, and t is the wall thickness.

One additional point merits attention here, and that is the problems associated with pumping the blanket fluid into and out of the magnetic field in order to carry out fuel recycle operations. If liquid lithium is used, its high electrical conductivity could make it hard to pump through the magnetic field because of magnetohydrodynamic effects. It is not known just how important this problem will be, but a high lithium flow rate requirement would lead to excessive pumping energy requirements.* For this reason, large cross section, low flow rate pipes will be used. Further, since the energy dissipated is proportional to the sine of the angle the flowing lithium makes with the magnetic field, this angle will be minimized. (This problem is, of course, not exclusively related to fuel recycle since the lithium would have to be pumped through the magnetic field anyway to get it to the heat exchangers even if tritium recovery were not required).

Engineering Considerations

For definiteness the Tokamak fusion device will be used as a basis for discussing some of the engineering features and problems of magnetically confined plasma devices. Laser-type fusion reactors will not be discussed per se, but many of the problems with the laser device are similar to those of Tokamak, major differences being the very high-powered lasers themselves and the absence of magnets. (However, it should be noted that some concepts of laser fusion devices do use magnetic fields to protect the first wall).

*The important problem has been treated in, "Analysis of a Recirculating Lithium Blanket Designed to Give a Low Magnetohydrodynamic Pumping Power Requirement", ORNL-TM-3756 (Sept. 1972), by A. P. Fraas.

Embrittlement, swelling, sputtering (erosion), corrosion, and radiation damage are important materials problems in common with all fusion devices. The problems associated with fuel recycle are also common to all of them.

Figure 8 is a conceptualization of an experimental toroidal fusion reactor power plant. Some of the components are identified on the figure. Further design information of use in this discussion is contained in Table 3. The information in the table is based on a 5000-MWt reference design produced at the University of Wisconsin.

An important design parameter of Tokamaks is the ratio of major-to-minor torus diameters, called the aspect ratio. This ratio sets the surface-to-volume ratio, which is important because volume is a measure of total power attainable, while surface area is a principal determinant in setting radiation and thermal loads on the materials used to contain the plasma. Since for a torus the surface-to-volume ratio is given by $4/d$, where d is the torus minor diameter, it follows that decreasing the minor diameter as much as possible for a fixed major diameter will help alleviate the above two important problems by providing a larger area over which to spread the thermal and radiation energy loads. The worst conditions will be attained when the major and minor diameters are equal. Thus, for a given power the torus major diameter should be as large as possible for a given minor diameter. However, other problems, such as costs associated with increasing magnet size and limits of material strengths rapidly become more severe as torus major diameter increases, and ultimately a balance among the conflicting design objectives must be struck. A major goal of the fusion reactor development programs is to establish an acceptable

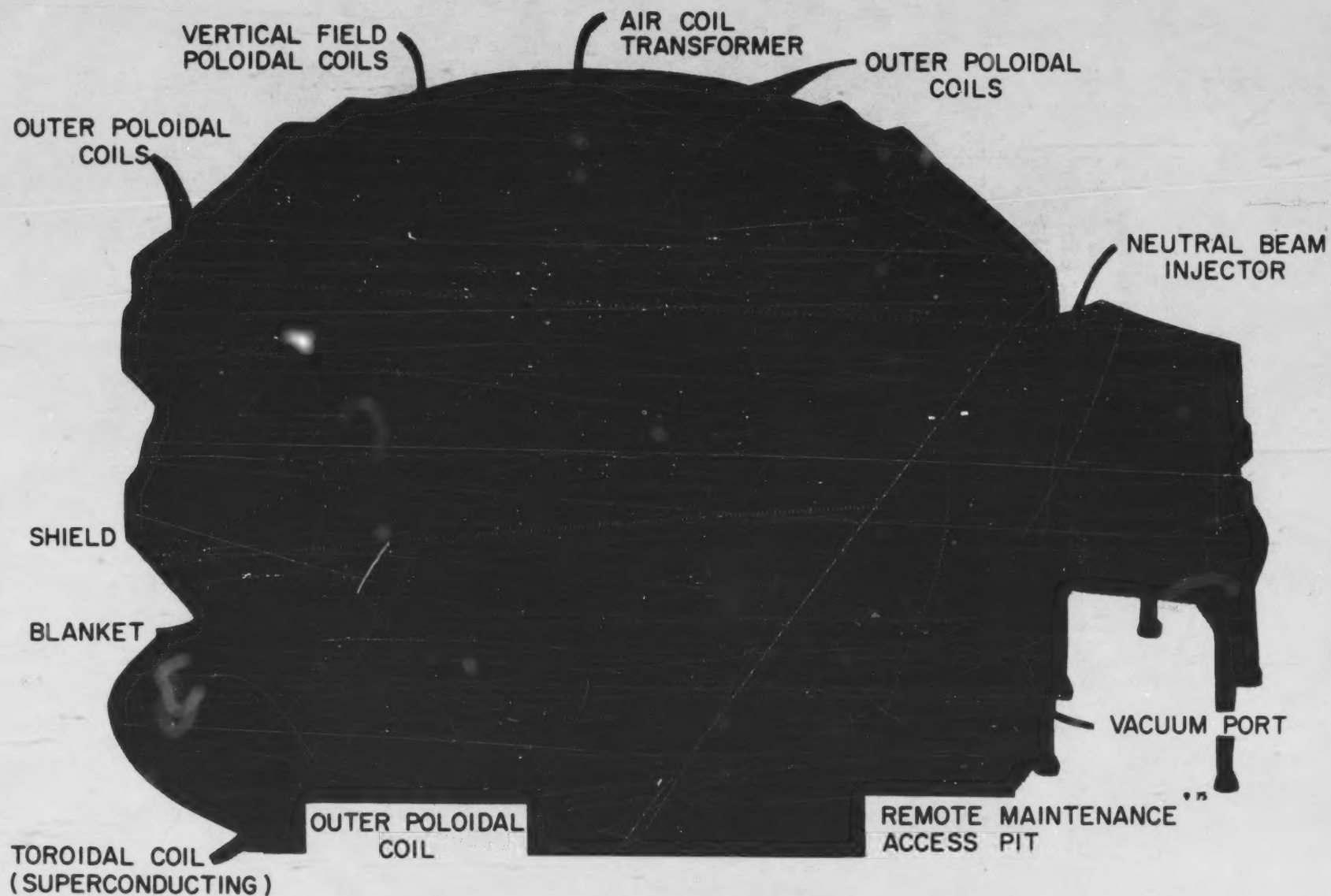


Fig. 8 CONCEPTUAL EXPERIMENTAL POWER REACTOR

TABLE 3 (continued)

Plasma Fuel Cycle Features

Fueling method	Injection of solid 20 micron radius ($2\text{H} + 3\text{H}$) pellets
Fueling rate	2×10^7 pellets/sec
Tritium production rate	1.05 kg/day
Rate of tritium removal by diffusion to divertor collection system	7.4 kg/day
Rate of deuterium removal by diffusion to divertor collection system	~ 5 kg/day
Percent fuel burnup per cycle	7.2
Breeding ratio	1.49
Operating cycle time	1.6 hours
"Thermonuclear burn" time	1.5 hours

Materials

Lithium	1,425 tonnes
Lead	16,500 tonnes
Copper	4,875 tonnes
Beryllium (if a molten lithium-beryllium fluoride salt is used)	180 tonnes
Chromium	2,850 tonnes
Nickel	2,250 tonnes
Iron	22,500 tonnes
Tritium inventory	~ 30 kg

System Temperatures

Lithium at the first wall	483°C
Sodium in intermediate (Li/Na) heat exchanger	411°C
Steam into turbine from Na/H ₂ O heat exchanger	297°C
Liquid helium to superconducting magnet	4.2°K

set or range of parameters for a practical and economical reactor design.

Figure 9 shows schematically the materials, dimensions and sequences used in the blanket, shield and magnet for UWMAK-1, the University of Wisconsin reference design. The magnet shield is shown as a combination of stainless steel, lead, lithium and B_4C . Some of the major engineering problems attending fusion reactors may be inferred from Figure 8 and Table 3. These are related to temperature, materials and stored (and latent) energy.

Temperature

Problems related to temperature involve both achieving and maintaining temperatures low enough for the magnets to be superconducting, and keeping temperatures and temperature gradients small enough that material corrosion and stresses are not excessive. On the other hand, there is some advantage to high temperatures because various kinds of wall damage are alleviated by high temperature annealing. The related problem of heat flux was alluded to earlier.

As shown in Figure 9, 316 stainless steel is the first line of defense against the plasma. It appears that it may not be practical to let the steel reach a temperature above about $500^{\circ}C$ because corrosion by the Li blanket will become a serious problem at higher temperatures. Fast neutron interaction with the stainless steel and other materials produces heat, and so higher temperatures, as does absorption of electromagnetic radiation from both the plasma and the blanket. These considerations point up the incentive to go to larger torus surface-to-volume ratios.

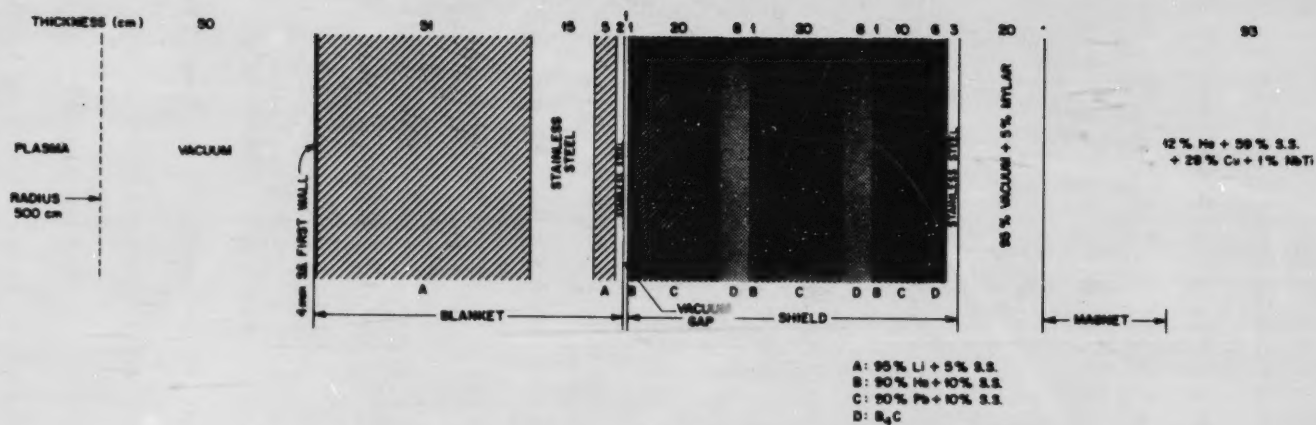


Fig. 9 SCHEMATIC OF UWMAK-I BLANKET, SHIELD AND MAGNET

Much of the complexity of the structure of the blanket and shield shown in Fig. 9 is aimed at keeping the heat flow low into the superconducting magnet. A radiation shield is needed to keep this load low enough to keep the refrigeration problem tractable. Lead will be the principal shielding material for this purpose. Unless the heat flow is kept low to the magnet, the refrigeration energy requirements for keeping the coils superconducting could exceed the energy produced by the fusion device.

Materials

Materials, broadly speaking, are at the heart of the problem of achieving practical fusion reactors (assuming that the fusion reaction itself can be shown to be attainable in a practical way). The superconducting magnets must be made of materials that can be fabricated and operated for many cycles. The inner containment wall must resist embrittlement, swelling, sputtering (erosion), lithium corrosion, high energy fluxes, and radiation effects. Other kinds of attack may also be important, e.g., hydriding and electrochemical reactions. Certain walls must be permeable to tritium, while others should be as impermeable as possible. Electrical insulation of extraordinary radiation damage resistance must be used--radiation doses of about 10^{22} nvt are expected. Neutron cross sections of materials of construction should be low, as should buildup of long-lived radioisotopes. Table 4 lists some of the factors related to materials problems.

Embrittlement of the stainless steel (S.S.) wall results from He gas formation by (n,α) reactions in the metal matrix, and from He gas collection at grain boundaries. This effect occurs when S.S. temperatures are below 500°C --the temperature range imposed by a corrosion

TABLE 4
MATERIALS CONSIDERATIONS

PROBLEM	SOURCE
Embrittlement	Helium accumulation in metals, especially the stainless steel.
Swelling	Radiation damage and accumulation of helium in the stainless steel.
Sputtering (erosion)	Neutrons and ions striking the first wall and knocking material off.
Corrosion	Reaction of lithium metal with containment walls (chiefly 316 stainless steel); reaction of stainless steel with F1 Li Be if molten salt is used in the blanket.
Radiation effects	Neutrons and radiant energy striking thermal and electrical insulation and copper used in the superconducting magnet.

rate of 1.5 to 2.5 tonnes/yr. of the S.S. by the lithium blanket at 500°C and an even higher rate of higher temperatures. In addition to He formation, transmutation of the stainless steel wall by reaction of neutrons with the constituent atoms may also be a source of embrittlement.

Swelling of the stainless steel is really another consequence of the same basic, and apparently unavoidable phenomenon, i.e., helium formation in the metal. Helium will be formed at the rate of about 300 atoms per million atoms of metal per year, so will reach about 600 atomic parts per million in the two-year life of the first wall. Added to the swelling from this source will be swelling from displacement of metal atoms caused by collisions with high energy neutrons. The rate of such displacements may be of the order of 18 per year, i.e., each atom will have been displaced ~18 times each year.

Sputtering will lead to significant first wall erosion. About 75% of the stainless steel erosion may be caused by the 14 Mev neutrons; other erosion mechanisms are impingement by deuterons and tritium, by scattered neutrons, and by ions of previously sputtered metal. As much as 0.22 mm per year may be lost from the first wall by the sputtering effect.

Radiation effects may be discussed separately, although in fact embrittlement, swelling and sputtering are all types of radiation effects. The principal other radiation effect could arise from increased resistance in the copper used to stabilize* the superconducting

*The word "stabilize" means that the superconductor (NbTi or NbSn) is in a copper matrix which both carries and supports it, and provides a mechanism for carrying the enormous current (~1300 amps/cm²) carried by the superconductor if it should become non-superconducting.

magnets. This could result from creation of point defects in the copper by radiation. However, this does not appear to be a severe problem; neither does radiation damage to the thermal and electrical insulators.

Before leaving this discussion of what have been primarily materials problems with the wall adjacent to the plasma--i.e., the first wall-- it is worth observing that the costs of fusion devices will be very sensitive to the lifetime of that wall. The entire reactor must be shut down and a large fraction of it dismantled (remotely because of the radioactivity) to replace the first wall. The two-year lifetime estimated for that first wall is a severe drawback to fusion devices.

The blanket and shield would weigh of the order of thousands of tonnes (Li + SS + Pb) for a 5000 Mwt power plant and so pose major structural support problems. These problems are further complicated by the very severe thermal gradients which must be maintained immediately adjacent to support structure. Radial pressures of the order of thousands of pounds per square inch are generated by the magnetic field which tend to dilate the coil, and the structural support must also retain these pressures. (Stainless steel appears suitable for this use).

System Energy

Still another useful way to discuss engineering considerations is in terms of energy stored in the system in various ways. The lithium blanket may be considered (in an accident situation) to react with water and oxygen to form LiOH, yielding about 329 kilocalories per mole, or

$\sim 6.7 \times 10^{10}$ kilocalories of chemical energy for a 5000 Mwt fusion reactor power plant.

The energy stored in the magnetic field may be about an order of magnitude less than the potential chemical energy production, i.e., about 10^9 kilocalories. This stored "magnetic energy" would be dissipated in about 6 hours from a superconducting magnet. However, if for some reason the magnet should start conducting normally, the high current density and resultant heat generation would cause the energy to be dissipated much more rapidly--and perhaps dangerously. To allow for this possibility the superconducting magnet may be made mostly of copper (75 to 80% of the cross section), with holes to accommodate the superconducting NbTi (or NbSn). There must be enough copper to carry the current safely in the normal conducting mode, and its resistivity must not be excessively increased by radiation effects. (NbTi is more promising than the possible alternate NbSn for use in the superconducting magnet because it is ductile at room temperature; however, NbSn will tolerate a higher magnetic field before becoming non-superconducting).

There is also the consideration of energy stored as radioactivity in the fuel (tritium) and in the materials of construction (principally in the stainless steel). This energy is qualitatively different from the chemical, mechanical and electromagnetic energy stored in the fusion reactor. It is different because of the way it interacts with and affects living things, and because of the way it is released. Thus, calories are not a very satisfactory unit in which to measure radioactivity. In the next section the environmental aspects of the radioactivity will be discussed briefly. There will be about 3×10^8 curies

of tritium in the entire (5000 Mwt) power plant system and about 10^9 total curies (largely from radioactive stainless steel) in the blanket structure. The ratio of radioactive stainless steel decay power to reactor power is about 5×10^{-3} so a 5000 Mwt reactor contains about 25 Mwt of stainless steel decay heat at shutdown.

The half-life of tritium is 12.3 years; the situation with stainless steel is more complex because a number of radioisotopes are formed. (However, the radioactivity level will drop to about 5×10^8 curies two years after reactor shutdown, 5×10^6 curies after 20 years, and 350 curies after 200 years).

Environmental Considerations

No real attempt to evaluate, or even present fully, the situation with respect to the environment will be made. The factors to consider are resource mining; thermal, chemical and radioactive pollutants released into the biota; esthetic factors, and in a broader sense, geographic factors.

Resource Mining

All of the materials for fueling and building the fusion reactors must come from the earth. The deuterium comes from the sea, so appears to present no direct environmental problems, though second and higher order effects from building the necessary isotope separation plants will be experienced. The lithium will presumably come mostly from brines, so the situation more or less parallels that for deuterium. The large amounts of iron, chromium, nickel, copper, and lead must be mined, and so some environmental damage must result, at least temporarily.

Thermal, Chemical and Radioactive Pollutants

The fusion reactor power plants will be heat machines (unless direct conversion becomes much more promising than at present), and so will be hard pressed to exceed 50% thermal efficiency. The UWMAK-1 concept discussed in this essay has an efficiency of about 30%. Thus, more than half of their thermal energy goes to the environment directly and locally as heat. This problem is common to all electrical power plants, and must be solved in a general sense.

There is no reason to expect any unusual amounts of chemical pollutants from fusion reactor power plants, although accidental release of lithium or sodium could cause severe local problems in the form of LiOH or NaOH. Concomitantly, large amounts of hydrogen gas could be released, causing an explosion hazard.

The amount of radioactivity in the plant has been discussed earlier. It is worth mentioning that tritium is the radioisotope most likely to escape from the plant, and both its relatively short half-life and its low-energy beta particle make it one of the least noxious radioisotopes. However, metal parts adjacent to the plasma must be replaced every 1 to 2 years, and sooner or later the entire fusion plant must be retired and dismantled, and the substantial amounts of radioactive materials which make it up must be disposed of.

Esthetic and Geographic Factors

Esthetic factors related to power production are usually associated with such gross insults as those from stripmining for mineral resources. These are important kinds of considerations. However, beyond these there is the more subtle factor of where should a large

power plant with its materials transportation system and its unsightly power distribution system be located. This is related to the geographic factor, and to a certain extent to safety. Power plants are usually very near the power users to keep transmission costs low. But from both an esthetic and safety point of view, it is desirable to have the power plant as remote as possible from large population centers. As a matter of fact, the problem of power plant siting is one deserving of considerably more attention than it is usually given. It is very complex, however, in that it contains economic, social and technological elements.

The Future

The practicality of the fusion reactor power plant concept has yet to be established, but a major effort is underway to see what can be accomplished. Thinking has already begun on exotic systems such as hybrids between fusion and fission reactors. The basic thought is that the fusion reactor, which rapidly produces copious quantities of neutrons, could be coupled to a fission reactor (e.g. a Molten Salt Reactor or a High-Temperature Gas-Cooled Reactor), which produces a high power density easily. In this concept it would not be necessary to develop the sophisticated fusion machine described above. However, there are many other problems related to coupling fusion and fission devices, and such hybrids are best left to future generations to develop.

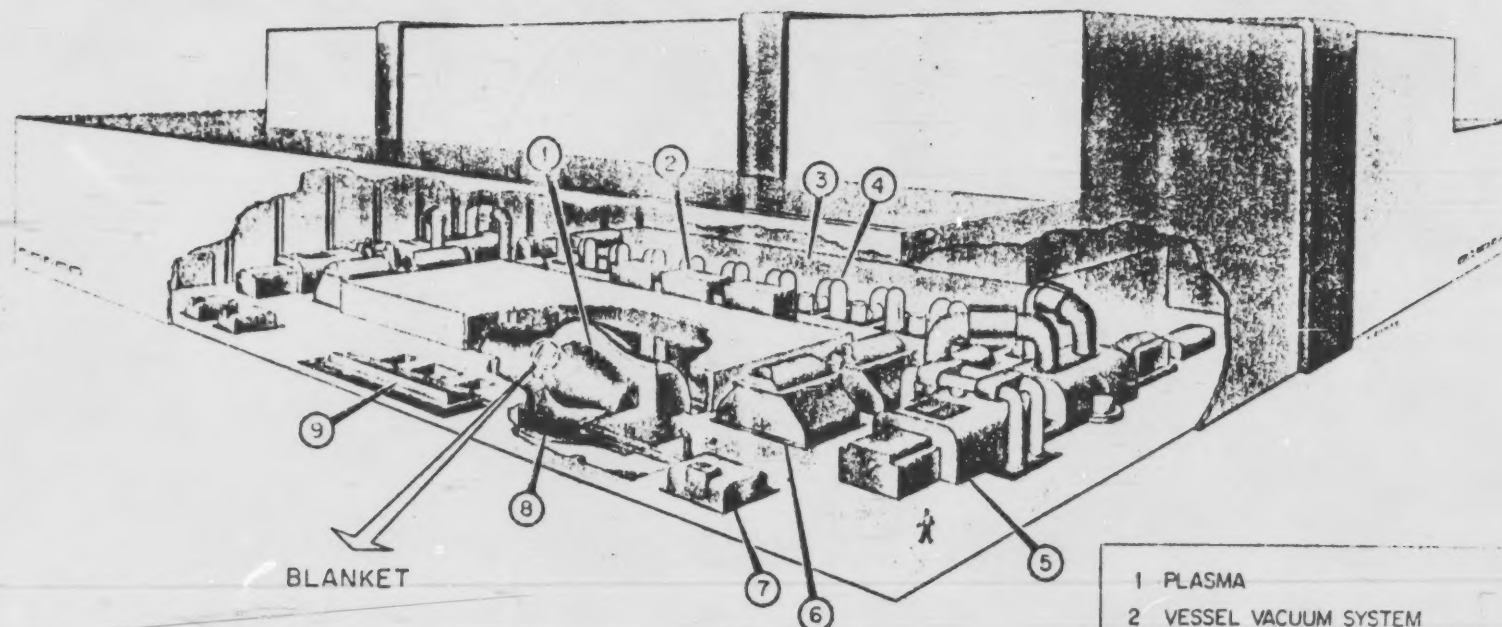
The time for realization of the potential of fusion power is probably more than 30 years away, and may be more nearly 50 years off--if it is attainable at all. The timetable set by ERDA is given below.

<u>Confinement System</u>	<u>Year of Completion</u>
Princeton Large Tokamak (PLT) Hydrogen plasma; magnet not superconducting.	1977
Tokamak Fusion Test Reactor (TFTR) Tritium - Deuterium plasma; no blanket; no ^3H recycle; magnet not superconducting; will meet Lawson criteria.	1980
Experimental Power Reactor (EPR) Plasma fuel recycle; partial blanket recycle; neutral beam injection; superconducting magnet; will produce ~100 Mwt.	1985

An artist's conception of the type of power plant to which fusion research may lead is shown in Figure 10.

Fig. 10 FUSION POWER PLANT

ORNL PHOTO NO. 70-10783A



- 1 PLASMA
- 2 VESSEL VACUUM SYSTEM
- 3 BLDG. SERVICE AND MAINTENANCE AREA
- 4 CRYOGENIC SYSTEMS
- 5 STEAM TURBINES AND GENERATORS
- 6 POTASSIUM TURBINES AND HEAT EXCHANGERS
- 7 TRITIUM REMOVAL SYSTEM
- 8 FUSION REACTOR
- 9 INJECTOR POWER SUPPLY

-404-

B I B L I O G R A P H Y

1. For a discussion of fusion reactor experiment types and their prospects for attaining the needed temperatures, ion concentrations and confinement times in the context of energy requirements see "The Prospects of Fusion Power," by W. C. Gough and B. J. Bastland in Scientific American, Vo.. 224, No. 2, pp. 50-64 (Feb. 1971).
2. For a knowledgeable discussion of fusion along the lines of this essay, but more sophisticated and complete, see "Controlled Nuclear Fusion: Status and Outlook," by D. J. Rose in Science, Vol. 172, No. 3985 (May 21, 1971).
3. For a simplistic discussion of energy and materials resources limitations, and of how fusion fills the needs for them, as well as a brief summary of fusion reactors themselves, see "Why Fusion?" by W. C. Gough in WASH-1165 (June 1970).
4. For a fairly up-to-date discussion of several of the more important fusion experiments see "Fusion Power: An Assessment of Ultimate Potential," in WASH-1239 (Feb. 1973).
5. The more sophisticated reader is referred to volumes 1 and 2 of Proceedings of the First Topical Meeting on the Technology of Controlled Nuclear Fusion, April 16-18, 1974, San Diego, Calif. These volumes are available as CONF-740402-P1 and -P2 from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22151, for \$13.60 each.

GENETIC AND SOMATIC RADIATION EFFECTS

By
DR. G. B. COSGROVE

**Pathologist, Biologist
Biology Division, Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37831**

***Operated for U.S. ERDA by Union Carbide Corporation**

GENETIC AND SOMATIC RADIATION EFFECTS

The sources of data for radiation effects on various mammalian species are the many university, government, and private laboratories with mammalian radiobiology programs. Numerically, the laboratory rodents, rats and mice, and to a lesser extent guinea pigs, hamsters, and rabbits, are used far more frequently for such studies than are other mammals. Rodents are economical, can be bred to give uniformity of reaction, are easy to handle, and have relatively short life spans. The larger mammals, cats and dogs, livestock, and primates, are much more expensive to obtain and maintain, require much more space, are more difficult to manage and care for, and have much longer life spans. In spite of these objectives, there are active centers of research with each of these species. One reason for this interest is the hope that experience in radiation biology gained by the use of higher or larger mammals will be more directly applicable to man.

There are a number of good radiobiological texts which are indicated in the general references and at specific points throughout the text of this chapter.

The biological effects of ionizing radiations are closely correlated with the type of radiation. The small high-energy particles such as electrons penetrate much more readily and do less damage by collision in tissues than do the larger, slower particles with courses characterized by heavy ionization paths. Low-energy external B rays penetrate only the superficial layers of tissues and do little or no damage to

deep structures. The source of the radiation, whether external or from internal deposition of radioisotopes, also profoundly influences the biological effect.

Within the animal there is a definite order of sensitivity of the various tissues and cells to the action of ionizing radiation (Cronkite and Bond, 1960). Exposures as low as 10-25 r of radiation can damage or kill the extremely radiosensitive cells such as lymphocytes, spermatogonia, and cells of the intestinal germinative epithelium. Only slightly less sensitive are the germinative cells of skin, colon, and stomach. Considerably larger doses are necessary for demonstrable morphologic effect on kidney, liver and endocrine glands. So-called radioresistant tissues are the adult central nervous system, muscle, bone, and collagen. Actually, there is no truly radioresistant tissue because an exposure of radiation can be attained which will damage any tissue. There is tremendous range between the lowest dose for cell damage (for lymphocyte, ~10 r) to the lowest dose for demonstrable change to bone (>5,000 r) (Warren, 1957).

Mammalian species also vary considerably in their susceptibility to radiation and this does not seem to have any definite relation to size, metabolism, primitiveness, or other commonly considered parameters.

Some or all of the effects of radiation on cells, tissues, and organs are obtained by appropriate doses of certain drugs and chemicals which are, therefore, labeled radiomimetic (Sternberg et al., 1958 and Asano et al., 1963). These fall into several different categories of chemical structure. Their radiomimetic effects vary, none being completely radiomimetic in that they fail to damage simultaneously the wide variety of tissues susceptible to ionizing radiation.

Acute Radiation Syndrome

When a group of animals of the same species is exposed to radiation, some or all may die if the dose is high enough. Doses that cause death in the subject population are called lethal doses, abbreviated LD. The percent of animals that die in a population exposed to a lethal dose is expressed as a subscript number after the initials LD (e.g., LD₅₀ means that the exposure in question will cause mortality averaging 50%). A third component of the LD designation is a number representing a time (in days). Any deaths occurring beyond this arbitrary time will be considered as outside the range of investigation. A sample of the full designation for the effect of a dose of radiation on a test group of animals might be LD₅₀/30; which means one-half the population was killed in the first 30 days after exposure. The adjective lethal is used in various modified ways when referring to radiation doses (e.g., sub-lethal = no mortality, mid-lethal = some but not complete mortality, and supra-lethal = doses in excess of that necessary to kill all).

Early death resulting from an exposure to ionizing radiation is due principally to cell damage in three important systems: the central nervous system (CNS), the gastrointestinal system (GI), and the hemopoietic (blood-forming) system (Bond and Robertson, 1957; UNSCEAR, 1962; and Quastler and Zucker, 1959). The reaction, course of events, and time of death differ as a result of damage to these different systems in the laboratory mouse. Very large doses of radiation (i.e., ~10,000 rad) with head exposure lead to "CNS death". This death is most rapid, occurring during irradiation with massive doses, or in periods from 1 to 2 days with doses lower in this range. The mechanism is direct injury to neurons (functional cells) in the vital centers of the nervous

system. If doses are approximately 2,000-10,000 rad, death occurs in 3 to 5 days and is due to damage to the lining cells of the gastrointestinal tract. If doses are approximately 500-1,000 r, deaths occur at 10 to 14 days and are due to damage to cells of the hemopoietic system. These three types of postirradiation death are often called the modes of radiation death. The actual changes in the involved systems will be discussed more fully later. In the mouse the three modes are associated with three fairly definite dose ranges and three fairly specific time periods. These distinctions between the modes may not be nearly as clear cut in other animal species, and death from GI and marrow injury are distinctly later in man. If the dose of radiation is high enough, the animal has been started on the road to all three modes of radiation death but will succumb with the pattern of the one that appears earliest. If an animal is exposed to a dose sufficient to cause CNS death, but if the head or brain is protected by shielding, the death will occur at the characteristic time period for GI death. Likewise, if a considerable portion of the GI tract is shielded during exposure to a dose of radiation sufficient to cause GI death (but not CNS), the death mode will be hemopoietic.

When the pattern of reaction of an animal to an acute dose of radiation is studied, it is found to be rather complex. This multiplicity of events and changes following radiation is manifested by certain signs and symptoms and occurs in a more or less patterned response. This pattern is termed the acute radiation syndrome when the exposure has been sufficient to cause serious hemopoietic and/or gastrointestinal damage. The acute radiation syndrome varies in different species of animals. In the mouse it is manifested by a series

of findings. For the first day or two after exposure the mouse appears well and may eat normally, but examination of the blood reveals a precipitous fall in the blood lymphocyte count. At about the 2nd to 4th day the mouse shows some indication of sickness and distress. If gastrointestinal damage predominates, there is diarrhea, rapid weight loss, and early death. If gastrointestinal damage is sublethal, a more prolonged course of weight loss, ruffling of fur, hunched posture, lack of activity, and lack of appetite is noted. Internal changes may be found by appropriate examination. During this period, the leukocytes remain at very low levels. The number of erythrocytes or red blood cells tends to remain normal, perhaps decreasing if hemorrhage is occurring, perhaps relatively increasing due to dehydration (insufficient water intake or some loss of fluid by diarrhea). The number of blood platelets, essential for blood clotting, decreases during this period. After 8 to 10 days, internal examination might reveal scattered hemorrhages in many tissues and organs, especially skin and the walls of stomach or intestines, also in brain, testes, lymph nodes, and indeed in any organ. Studies of blood or tissue for bacteria would reveal their presence in large numbers. They are carried by the circulation, entering principally from the GI tract, and are not destroyed because of decreased resistance of the body defense mechanisms (leukocytes, immunity, etc.).

From 10 to 14 days, death occurs in those individuals who do not have effective recovery in the hemopoietic organs. This recovery is manifested by increases in numbers of leukocytes and platelets sufficient to counteract the infection and hemorrhage which are the chief causes of death in this period. Most of the animals that survive the

14-day postirradiation period will live through the 30-day period after irradiation and go into a long latent period before abnormalities appear. In man, we have a less neat pattern, and marrow death is later (i.e., 20 to 45 days).

Man has simultaneous signs and symptoms of hemopoietic damage (as above), GI damage (such as nausea, vomiting, loss of appetite, abdominal pain), and nervous system symptoms (such as headache, dizziness, and irritability) (Gerstner, 1958). Man can describe how he feels, which other animals cannot do. Therefore, man's list of indications of the presence of the acute radiation syndrome is more complete.

Embryo: Radiation effects on the embryo vary considerably, depending upon the stage at which it is irradiated and what organs are in rapid-formation phase at that time (Rugh, 1963). Three periods are usually separated. Irradiation during the pre-implantation period before the placenta forms is accompanied by a high likelihood of death in utero even with doses as low as 200 r, but survivors are usually normal. If radiation occurs during the second period, when the major organs are being formed, there is considerably less death in the uterus, but much death at time of birth. This is the stage in which many abnormalities result from irradiation. Finally, if radiation occurs in the late fetal period, there is little death in utero or at time of birth and no large percent of birth abnormalities.

Delayed Effects of Irradiation

The literature on delayed effects of radiation is far less voluminous than that on acute effects in mammals. Some summaries are those of Odell, et al, 1960-61; Abraham, 1962; and Loutit, 1962. Extensive experiments

on delayed effects in mice are reported by Upton, et al, 1960, and in rats by Lamson, et al, 1957-58.

Survivors of acute radiation exposure undergo late changes. When considered as a group, they have a different disease pattern and shorter life expectancy than an unirradiated group of similar animals. This indicates that they are left with some damage after apparent recovery from the original radiation exposure. This residual damage is called irreparable injury. The other component of injury is called reparable because repair of it occurs. An animal with irreparable injury shows a lessened resistance to subsequent exposures to radiation or other injurious agents (Hursh, et al., 1959).

In animals surviving an acute whole-body exposure to radiation, there is a long latent period lasting months or years depending upon the life span of the involved animal -- during this latent period very little further mortality occurs -- there then comes a time when individuals begin to die off and group mortality is fairly rapid from that point on. This period of late mortality is called the period of delayed effects of radiation. At this time, the diseases of aging appear both in the control population and the irradiated population, and also some increase in various diseases due to irradiation is noted. Radiation shortens the life span of the involved group in proportion to dose. Throughout the later months, in groups of animals exposed to fairly heavy doses of radiation in earlier life, we find a decrease in average weight of the group and a decrease in vigor and vitality when compared with controls. They are less resistant to stresses of all types, and the types of diseases recognized in controls tend to occur earlier in the irradiated groups. There are, however, marked species differences

in these effects and also within species there are strain differences in the effects. There is some argument as to whether completely new diseases appear in irradiated populations, i.e., diseases which are not found in control populations.

Effects on Skin, Hair, and Eye

A number of interesting effects which are not responsible for death of the animals are noted during this time. The late effects of radiation on skin, hair, and associated glands are noticeable. If the dose of radiation has been fairly high, the skin may show scarring, considerable loss of glands, lack of sweating or sebaceous secretion, and even chronic radiation dermatitis with subsequent ulceration of the epithelium. There may be complete or partial, temporary or permanent, loss of hair. The hair, especially in small mammals, may gradually turn gray and finally white. This graying of fur occurs only in the areas of skin exposed to radiation; shielded areas do not show graying. The areas that are in active hair growth at the time of the irradiation exposure are the areas which show the greatest graying at later dates. The rapidity of graying and the final severity tend to be correlated with the amount of radiation the hair follicles were exposed to originally.

In certain strains of mice, eye changes are very important. Iris atrophy has been noted after irradiation. In mice and other mammals, there is considerable damage to the lens of the eye with moderate to high radiation doses and this is followed by the development of cataract. This is an opacity of the lens which does not transmit light well. Cataract formation is a direct effect of radiation and does not appear in shielded eyes. The severity of the cataract and the rapidity with

which it develops are proportional to the amount of radiation exposure. Neutrons are more damaging to the lens of the eye than X or gamma rays.

Degeneration, Infection, and Neoplasia

The more serious diseases which contribute greatly to the accelerated mortality of an irradiated population include degenerations, infections, and the formation of tumors.

Degeneration: The most serious degenerations are those occurring in blood vessels. This change may be found in the vessels throughout the body and consist of sclerosis of the blood vessel wall. Another very important type of degenerative late effect of radiation is the formation of scars in the glomeruli (the functional filtering elements of the kidneys). In mice and other mammals, doses of radiation at the LD₅₀ level or greater are followed many months later by this condition. In some strains of mice this condition is not found to any degree in unirradiated animals. In other strains it does occur spontaneously with aging. The glomerulus is a vascular structure and there may also be associated changes in the adjacent small arteries. Radiation glomerulosclerosis is a direct effect of radiation since it does not occur in kidneys that are shielded from radiation. When the animal is irradiated at a very young age, the subsequent glomerulosclerosis is much more severe. Deaths due to glomerulosclerosis are accompanied by the findings of uremia. These are: fluid retention, anemia, and accumulation of nitrogenous wastes in the blood.

Infection: Heavily irradiated animals probably have a lowered resistance and a greater susceptibility to infection than controls do, since there seems to be an increased incidence of infection such as pneumonia, abscesses, enteritis, middle ear infections, etc. The

reverse may be true after low level irradiation (Sacher and Trucco, 1962).

Neoplasm: The occurrence of tumors (neoplasms) is common in irradiated animals. The benign types of neoplasm do not ordinarily threaten the life of the affected individual, while the malignant types will invariably kill the individual if enough time elapses. They are named depending upon the organ that they involve, the tissue from which they arise, and whether they are benign or malignant. Cancer is the general term for malignant tumors. In radiation biology, the tumors are often subdivided into two major groups depending on whether they arise in the blood-forming tissue, in which case they are called reticular tumors (leukemia or lymphoma), or whether they arise in any of the other tissues of the body, in which case they are called nonreticular tumors.

Leukemia and lymphoma seem to be very important radiation-associated diseases. Extensive studies on these diseases in many different irradiated animal species are being carried out. In mice there are three general types of leukemia or lymphoma that develop in controls and also in irradiated animals (Dunn, 1954). Starting a few months after irradiation and reaching peak incidence before one year is the thymic lymphoma. The second type, somewhat later in average appearance time, peaking at 12 to 15 months in irradiated groups, is myeloid leukemia. The third group is a heterogeneous collection of the so-called late leukemias and lymphomas which have peak incidence at about 15 to 18 months. There is a fairly characteristic picture with each of these three types of reticular neoplasm when the animal is subjected to autopsy and histological examination of the tissues. The thymic lymphoma usually originates in the thymus, but often spreads to involve other hemopoietic

organs and also many other organs of the body including liver and kidney. The predominant cell is an immature, abnormal appearing lymphocyte. The animals usually appear well nourished but undergo a rapid course ending in death. In myeloid leukemia, the principal involvement appears to be in the spleen and liver with marked enlargement of these organs. There is some secondary involvement of lymph nodes and other reticuloendothelial structures. The blood in this condition shows an increased number of the leukemic type of cells, whereas the blood in the other two main types of reticular tumors does not routinely show abnormal cells. Necrosis of the bone marrow is often associated with myeloid leukemia. The third group of leukemias and lymphomas is predominantly a mixture of reticulum cell tumors and lymphosarcomas. The cell types vary in these and the chief organ involvement often is quite variable. They usually occur as very large, rapidly growing white or yellowish nodules in the involved organs. They may involve many organs simultaneously or be largely confined to one area.

Leukemias and lymphomas of the thymic and myeloid types are both markedly increased by radiation in certain strains of mice and in certain other animals. If radiation doses are quite high, the incidence of these diseases in survivors is markedly reduced. The incidence of the late leukemias and lymphomas is not obviously influenced by radiation in most strains of mice. All three types also are markedly influenced by the age, by the sex, and by the hormonal status of the involved animals. The incidence of some can be increased by repeated and properly spaced radiation exposure.

Nonreticular tumors of some organs are increased after irradiation in certain species and strains of animals. Tumors of ovary, breast,

pituitary, liver, adrenal gland, orbital gland, bone, connective tissue, uterus, and skin are in this category. On the other hand, tumors of the lungs and bile ducts do not appear to be increased after whole-body irradiation in mice. Increased tumor incidence is often a direct effect of radiation since it will not occur in such cases when the target organ is shielded. In a few types of tumors, an indirect effect of radiation is manifested by an increase of tumors of the target organs even though they are shielded. In this category are certain types of lymphoma, ovarian tumors, pituitary tumors, and breast tumors. In such cases the associated endocrine organs usually have to be exposed if tumor is to be expected in the unexposed target organ.

Most forms of tumors tend to occur late in life in control and irradiated animals, i.e., they have a long latent period. Irradiation accelerates the onset of the tumors so that the peak incidence is usually some months earlier than in controls.

Radioisotopes

Radioisotopes, when ingested, are responsible for the induction of various types of tumors (Odell and Upton, 1961). The type of tumor, the location, whether benign or malignant, and the time of occurrence are greatly dependent upon several characteristics of the isotope. Isotopes tend to follow physiologic and metabolic pathways and have certain preferred sites of deposit where they accumulate. There is considerable variation in the radiations emanating from them, some radiations being very penetrating in tissues and other very weak. The state of the animal at time of isotope ingestion (e.g., rapid growth) also has considerable effect upon the deposition of the isotope. A number of the bone-seeking isotopes and those which give a fairly high degree of generalized radia-

tion induce leukemia and lymphoma. Many of those which are inhaled into the lung induce lung tumors; thyroid seekers yield thyroid tumors; and strontium and related compounds yield an increase of bone tumors.

Radioecology

The study of radiation effects on naturally occurring plant and animal communities is called radioecology. Such studies differ markedly from the rigorously controlled laboratory experiments on plants and animals but will be of increasing importance. The problems of radioactive waste disposal and accidental contamination will become more pressing. Some sites of radioecology studies are Oak Ridge, Tennessee; the ERDA Savannah River Plant in Georgia; Brookhaven National Laboratory; and the Hanford works in Richland, Washington. White Oak Lake bed in the drainage area of Oak Ridge National Laboratory has accumulated radioisotopes. Selected groups of plants, invertebrates and vertebrates are being studied there (Krumholz, 1954). In general, the response of plants is variable, most being radioresistant, but pines are somewhat radio-sensitive (Woodwell, 1962). Levels of radioactivity in plants exposed to isotopes were higher than normal. Some invertebrates concentrated radioactivity in their tissues. There were reductions in certain invertebrates populations in the contaminated areas. Some fish species received considerable yearly doses of radiation, had slowed growth rate, and were gradually disappearing. Other animals accumulating radioactivity were turtles, ducks, muskrats, and woodchucks. Snakes, bullfrogs, herons, raccoons, and squirrels did not tend to accumulate as much. Vertebrate skeletons tended to accumulate much more radioactivity than did the soft tissues. The importance of contamination in nature arises from the possibility of contamination in the food chain with concentration of

radioactivity in certain organisms which are later eaten directly or indirectly by man.

Radiation Effects on Man

The ever-present natural sources of radiation include cosmic rays; radiation from soils, rocks, etc.; and from internal radioisotopes such as uranium, K_{40} , and C^{14} which are present in varying amounts in all living organisms. Such exposure amounts to 0.1 rem/year on the average in many, but varies widely in different altitudes, climates, and geological areas. Man is often exposed to medical or other artificial sources during health examinations, shoe fittings, wearing of luminous dial watches, and watching television. A few persons are subject to occupational exposures in research or industry where radiation sources used. The "permissible dose" for this group is considerably higher than for the population as a whole (Federal Register, 1960).

Acute Radiation Syndrome

Considerable information on the picture and course of the acute radiation syndrome in man has been derived from studies on persons accudebtakkt (war, occupation, or research accidents) or medically exposed (Cronkite and Bond, 1960). Many such cases have been exhaustively followed (Gerstner, 1958). Due to the tremendous disruption and confusion in the Japanese cities after the atom bombings, studies of only limited value were made at the time (Oughtersen and Warren, 1956). From such cumulative information, a good picture of acute human-radiation disease emerges. The whole body LD_{50} exposure is not definitely known, but is felt to be in the 400-500 r range. The earliest symptoms are of nervous system origin. Mental depression with associated nausea and

vomiting are noted. Early diarrhea indicates gastrointestinal damage. Blood changes indicative of bone marrow damage appear at about 2 weeks. These are accompanied by hemorrhage if exposures are serious. Attempted treatment will depend on the exposure, if known, and certainly on the severity of the clinical signs and symptoms. Acute radiation exposures in humans have been used medically in attempts to treat hopeless diseases such as leukemias or widespread cancers. It has also been used in cases of organ grafting, especially kidney, to reduce the possibility of graft rejection. Finally, radioisotopes have been injected into abnormal tissues (tumors, etc.) for which they have a greater affinity than they do for normal tissues in hopes that the concentrated radiation resulting will be therapeutic.

Delayed Effects

Information on the delayed effects of radiation on exposed humans is derived from several sources (see Behrens, 1959; Ellinger, 1957; UNSCEAR, 1962). The pioneer workers in radiation, principally medical, were unaware of the dangers for a time. Numbers of them were severely exposed and suffered important consequences, especially ulcers, skin degeneration, and skin cancers of the overexposed areas such as the hands.

Even earlier, a high incidence of lung cancers had been noted in workers in certain European mines (Schneeberg and Joachimsthal). It was subsequently found that radon gas emanating from ores in the mines was present in dangerous concentrations.

An early industrial exposure was in the radium-dial painting of clocks. Paint containing radium was carried to the lips by moistening the tips of the fine brushes used. The radium was swallowed and absorbed,

settling in the bones. Much later, bone tumors and severe bone diseases appeared in many of these people.

At about this time, radiation treatment of several diseases was in vogue. Most important was the treatment of enlarged thymus glands in the upper chest cavity. These occurred in children and were irradiated through a port exposing the thymus and including the lower neck. An increased incidence of thyroid gland tumors was noted in later years in these children. Another important group involved adults irradiated over the spine because of spinal arthritis. Exact data on late effects in this group was difficult to obtain but an increase in tumors and leukemias was noted.

The Japanese survivors of the atom bomb are being followed very closely for the development of late effects of radiation. Marked increases in leukemia and some forms of tumors were found after a few years in heavily exposed groups. This trend has leveled off in recent years.

Accidental Exposures

Research and technical workers in radiation laboratories have been involved in a number of accidents involving radiation overexposures (WHO, 1960). Among others, there have been accidents at Los Alamos with three fatalities. One at Oak Ridge involved eight people with no fatalities. A reactor accident in Yugoslavia in 1958 involved eight persons. Five of these were treated in Paris by the use of human bone marrow or fetal liver injections. There was one death. There was an accident in Lockport, New York, involving radiation from a giant radar tube which resulted in high partial-body exposures to some persons.

An accidental fallout exposure occurred following an atom-bomb test in the Marshall Islands in 1953 (Cronkite et al., 1956). A number of natives, Japanese fishermen, and U. S. personnel were exposed to fallout composed principally of beta emitters. Skin and hair changes appeared. Some persons receiving between 100-200 r exposures showed minor internal changes for a time.

Observers are closely following survivors of all these recent accidental exposures and much valuable information on late effects should result.

Low Doses and Protracted Doses

Of most practical human importance are the studies on the somatic effects of small, protracted radiation exposures. In people this information is very incomplete and will require many years for verification due to the long life span of man. The atom bomb survivors are the most useful group for present and future data accumulation. Most of our knowledge in this area will continue to be derived from laboratory experiments with the usual problems of extrapolation to man.

Some general conclusions can be made from the available information on man and animals:

- 1) The life shortening effect of radiation decreases with decrease and protraction of the dose until at lower doses it is not significantly different from unirradiated controls.
- 2) Likewise, the excessive tumor incidence in irradiated groups of mammals approximates control levels in the lower dose ranges. Some very radiosensitive organs such as ovaries of mice tend to become tumorous at low doses but the effect of very low doses is still uncertain.

3) Non-lethal effects such as greying of hair, damage to the lens of the eye, and general body effects on weight and activity disappear at very low doses.

Species variability, sex, age, dose rate and type of radiation are all responsible for variations in susceptibility to the above effects.

Genetic Effects

The cell nucleus contains chromatin arranged in chromosomes and there are many genes on each chromosome. The chromosomes and genes of the male and female reproductive cells carry the hereditary characteristics to the offspring. Genetic effects of irradiation are possible when the genes or chromosomes of sperm or ova are damaged and the damaged genetic material is passed on to offspring. If the damage is limited to genes, their function is altered and the characteristics they determine in offspring may be altered. Damage to chromosomes themselves result in extensive areas of altered chromatin, which is divided evenly during the formation of the fertilization cell. The damage shows as physical alteration in size, shape, or numbers of chromosomes.

Available information on genetic effects of radiation comes from experiments on a wide range of life-forms from lowest to most complex. Most available data of potential usefulness in estimating effects on man come from mouse experiments. There is little direct human data, the best of which is the family history of irradiated survivors of the Japanese atom bombs.

Summary of useful information based principally on mouse data (UNSCEAR, 1972):

A. Gene effects - If the damaged genes survive and reproduction occurs the effects are manifested through many generations.

1. Male parent irradiated.

- a) By acute sizable radiation dose. Yield of mutations estimated at 100-5,000 recessive mutations/rad of radiation/million offspring.
- b) By low dose or protracted radiation yield about 1/2 of "a".

2. Female parent irradiated.

- a) By acute sizable radiation dose. (The effect depends on the time of conception after the radiation). If early post R-conception the effect is about twice that in the male falling with time of conception.
- b) Low dose acute. Effect about 1/3 of "a".
- c) Protracted dose. Effect about 1/20 of "a" falling to nil in later conceptions.

B. Chromosome effects - seriously damaged chromosomes are eliminated early so not involved in conception, or only in first (few) generations.

1. Male parent irradiated.

- a) Acute radiation - yield of abnormalities proportioned to dose when fairly sizable doses, average about 30/rad/million for balanced translocation, and twice that for unbalanced translocation.
- b) Low dose irradiation. Yield about 1/3 of "a".
- c) Protracted irradiation. Yield about 1/4 of "a".

2. Female parent irradiated.

- a) Similar to male yield for acute dose but little data

available for balanced translocation, but about 3 times as many for unbalanced. "b" and "c" like "a".

Application to man:

- 1) Man may be about twice as sensitive as the mouse.
- 2) Estimate is that approximately 50 rem acute or 100 rem protracted dose necessary to double yield above background mutation level.
- 3) Committees estimate 1 rem/generation dose would result in only a small % of the number of mutations occurring spontaneously.

Offspring effects when parents are irradiated; studied in atom bomb survivors. No significant effect on:

- 1) Incidence of abortion.
- 2) Incidence of stillbirth.
- 3) Incidence of congenital defects.
- 4) Incidence of childhood deaths.
- 5) Sex ratio changes.
- 6) Average birth weight.

More pessimistic views are taken by some scientists, e.g., J. W. Gofman and A. Tamplin, who regard the present permissible radiation exposures excessive in terms of production of future genetic disease.

RECENT REFERENCES

- Arena, V., 1971, Ionizing Radiation and Life, Mosby, St. Louis.
- Berdjis, C. C., 1971, Pathology of Irradiation, Williams and Wilkins, Baltimore.
- Blair, H. A. (ed.), 1967 reprint, Biological Effects of External Radiation, Hafner, NY.
- Casarett, A. P., Radiation Biology, Prentice-Hall, Englewood Cliffs, N.J.
- Coggle, J. B., 1971, Biological Effects of Radiation.
- Etter, L. B., 1965, The Science of Ionizing Radiation.
- Fabrikant, J. I., 1972, Radiobiology.
- Goldman, M. & L. K. Bustad, 1972, Biomedical Implications of Radiostrontium Exposure, ABC Symp. Ser. 25, CONF-710201, US-ERDA, Office of Information Services, Oak Ridge, Tennessee.
- Pizzarello, D. J. & R. L. Witcofski, 1975, Basic Radiation Biology, Lea & Febiger, Philadelphia.
- Prasad, K. N., 1974, Human Radiation Biology, Harper & Row.
- Rubin, P. & G. W. Casarett, Clinical Radiation Pathology, Saunders, Philadelphia.
- Sagan, L. A. (ed.), 1974, Human and Ecologic Effects of Nuclear Power Plants, Thomas, Springfield, Ill.
- Schwartz, E. B., The Biological Basis of Radiation Therapy, Lippincott, Philadelphia.
- Shore, B. & F. Hatch, eds., 1969, Biological Implications of the Nuclear Age, ABC Sympos. Series 16, CONF-690303, US-ERDA, Office of Information Services, Oak Ridge, Tennessee.
- Tobias, C. A., 1974, Space Radiation Biology and Related Topics.

ENERGY ECONOMICS

By
DR. CLAUDE G. PONCELET

**Scientific Advisor, Energy Action Office
Power Systems Company
Westinghouse Electric Corporation
P.O. Box 355
Pittsburgh, Pennsylvania 15230**

463

ENERGY ECONOMICS

I. Introduction

Energy economics is a key element in an overall perspective on energy, not only because of the importance to the consumer of the cost of energy in its various usable forms, but also because energy economics is a major factor, along with technology, resources, and environmental and public health impacts, in dictating the mix of energy sources that make up our national energy programs and because energy economics ultimately influences to a large extent the status and general health of our overall national economy. The subject of energy economics encompasses both the costs of providing energy in a usable form to the consumer, be he an industrial processor, a home-owner or an automobile owner, as well as the aspects of financing of energy systems by the industries that generate and distribute energy to the users. Because of time limitations I will concentrate in my talk on the first aspect, that is energy costs, although I will make reference when appropriate to financing requirements and the dependence on capital markets.

Although energy has many forms, practical end-uses of energy in our society relies essentially on energy in the forms of electricity, heat, or the potential energy of chemical fuels, such as gasoline (Chart 1). Today, about 74% of our energy use is in the form of chemical fuels and 26% in the form of electricity. Currently, we generate useful heat either by burning chemical fuels, or electrically, and about 35% of our energy

use constitutes direct production of heat. On the left of the chart are the current primary energy sources, showing their utilization in the production of end-use energy forms. Note that while the traditional fossil fuels--oil, gas and coal--are used to produce all three forms of end-use energy, the nuclear fuels and geothermal sources are limited to the production of heat and electricity, while hydro-electric power is limited to the generation of electricity. Solar energy can be used for the production of heat, electricity, or chemical fuels through the process of bio-conversion. On the right of the chart are end-uses of energy. Today, transportation accounts for about 33% of our energy end-use, industrial processing and manufacturing accounts for 37%, while space and water heating accounts for 24%.

Of course as individual consumers, we are concerned with the cost of energy which we directly purchase and for perspective it is useful to consider what a family spends monthly on direct energy purchase. Such data vary widely with region and family living habits and to avoid a contestation, I have opted to use my own family expenditures (Chart 2). We have four children, we keep our house at 66°F during winter months, use no air-conditioning, use a gas hot water heater, an electric stove, and with my wife and myself both working, utilize two cars. Note that gasoline makes up the bulk of our monthly energy bill, while electricity constitutes only 16% of our monthly bill. Note that energy costs also directly influence the cost of manufactured goods, foods, and services and therefore, have an additional indirect effect on the monthly family budget.

In general, the cost of energy delivered to the end-user can be broken down into several distinct components (Chart 3). The first is

the cost of the facilities and associated equipment, such as an oil refinery or an electric power plant, required to produce a particular form of energy. These facilities are usually financed through loans or the sale of bonds or stocks and the monthly or yearly energy end-use cost reflects this financing cost, that is, both principal and interest. The second component is the cost of the primary fuel itself; for example, crude oil, coal or uranium. Next is the cost of operating and maintaining such energy facilities. The fourth component relates to the cost of transmitting or distributing the energy to the ultimate consumer; for example, via pipelines or electric transmission lines. The last cost component on the chart I have labeled administration cost and it includes general administration, customer billing, etc. The contribution of each of the five components to the end-use cost will, of course, vary with the energy form as well as with the primary energy source.

In what follows, I will consider in some detail the costs, today and as we anticipate for the future, of electricity, heat and chemical fuels. Before I do so, I would like to consider again, in general terms at this time, the make up of the capital equipment financing cost. This cost component includes what is referred to as the capital cost, that is the actual cost of building and constructing the facility and the financing or interest costs (Chart 4). The capital cost itself can be broken down into a number of typical components. First is the direct cost of purchasing equipment and of construction, including labor cost. Next is a component denoted contingency which is an allowance provided for unforeseen or unpredictable costs. Professional services refer to the cost of consultants, environmental surveys, etc. Construction of a large energy facility typically requires several years, at times up to ten years and

substantial components of the capital cost are the escalation in cost during construction as a result of inflation and the interest paid during construction on the capital required for construction. These interest payments are separated from the normal financing costs during the lifetime of the facility since typically no energy and therefore, no income, is generated by the facility during the construction period. These last two items are directly dependent on the rate of inflation, the current interest rates, and the length of the construction period and can constitute a major portion of the total capital cost. As we shall see presently, they constitute nearly half the total capital cost of large power plants built today. A large energy facility will typically be financed over a period of 15 to 30 years. As shown on the chart, the accumulated financing costs, or interest payments, can amount to two to four times the capital cost itself. The monthly or yearly energy end-use cost includes both the capital cost and the financing cost. Note that typically the actual cost of equipment is a small fraction of these costs while the interest or financing cost dominates.

II. Electricity

Let me now turn to the economics of electrical power generation. The cost of electricity to the consumer includes the so-called bus-bar cost, or the cost of generating electricity at the power plant as well as the costs of transmission and distribution and the administration costs referred to earlier. The bus-bar cost includes the capital financing costs, the fuel costs, and the plant operation and maintenance costs. Although this varies with transmission and distribution distances and other regional factors, the bus-bar cost on the average represents roughly 50-60% of the

electricity end-use cost. In what follows, I will focus on the bus-bar cost, that is, the cost of generating electricity at the power plant site.

Chart 5 shows, in simplified equation form, how the cost of electrical power generation is computed. The bus-bar cost is given in dollars, or cents, per kilowatt hour (Kwhr), that is the cost of generating one kilowatt for one hour. Note that a family of four on the average consumes in a house or apartment about 11,000 Kwhr per year. The first term on the right hand side is the capital financing cost. The numerator includes the capital cost in dollars per kilowatt of generating capacity of the power plant, times the yearly financing charge, which for electric power plants amortized over 30 years is about 15% of the capital cost, per year. The denominator is the equivalent number of hours during the year during which the plant generated power at one hundred percent power capacity. There are 8760 hours in a year and the capacity factor represents the fraction of the year during which the power plant operated at equivalent full power. The plant capacity factor is an important factor in determining electrical power economics since a utility must pay the plant financing costs whether the plant is generating electrical power or not. The second term in the equation is the fuel cost. This cost must reflect the entire fuel cycle costs, that is, not only the cost of mining or extracting fuel ore but also the cost of transporting and processing the fuel in the form required for use in the power plant. The last term in the equation is the operation and maintenance (O & M) cost and it includes such costs as staff payroll, supplies, insurance, services, etc. Again, these costs apply whether the plant is generating electrical power or not.

Note that the total bus-bar cost is the sum of the three cost components. Thus, a plant with a higher capital cost but with a lower fuel cost could generate electrical power at a net lower cost than a plant with lower capital cost but a higher fuel cost. The plant with a higher capital cost, however, while it would be advantageous or cheaper for the consumer does require the utility to raise more capital and the ability of a utility to raise capital may be severely constrained, particularly in a tight money market such as today's. To use a simple example, adding up your monthly car financing payments and your monthly gasoline and maintenance bills, you may pay less per month if you purchase a more expensive, but better gas-mileage automobile but the banker may be unwilling to make you a loan for the more expensive car.

Let me now turn to a consideration of actual costs of generating electrical power with currently operating power plants (Chart 6). This chart shows the actual costs, as reported by electric utilities, of generating electricity in 1975 in oil-fired, coal-fired and nuclear power plants. The costs are in cents per kilowatt-hour and are averages for the country. Also shown are the equivalent direct costs for a family of four. Of the three types of power plants, nuclear plants are currently generating electrical power at the lowest cost followed by coal and oil. Oil-generated electricity costs are roughly three times nuclear-generated electricity costs representing about a \$40 per month difference for an average family of four. Note that the major differences between the plants occur in the fuel costs. Although nuclear plants provided only 9% of the electricity generated in the United States in 1975, their replacement by fossil-fired power plants would have cost the U.S. consumers over \$2 billion in higher electricity bills. Note also that nuclear fuel cycle

costs constitute about 28% of the total bus-bar cost while coal and oil fuel prices constitute about 60% of the total bus-bar cost. Hydro-electric power costs, now shown on the chart, vary from region to region and are lowest, being typically in the range 0.3 to 0.9 cents/Kwhr.

Fuel costs have been soaring in recent years and in the next chart (Chart 7), I have computed the cost of electricity assuming a doubling of the fuel cycle cost with other costs at their 1975 levels. Note that the differentials between oil, coal and nuclear are increased. For an average family of four, doubling of the fuel cycle cost increases the monthly electricity bill by \$38 for oil, \$18 for coal and \$6 for nuclear.

Let me now turn to the projected cost of electricity generated by power plants going on-line in 1985, that is, plants ordered today or within the next few years. There is a good deal of uncertainty in estimating capital cost and future fuel costs and therefore, these projections must be looked upon as merely best estimates. In the last 12 months, there have been many estimates of power plant capital costs and our analysis has been based on taking a mean or average of these projections. Note that the only types of power plants ordered today are coal-fired or nuclear Light Water Reactors (LWR) and I will restrict this analysis to these types of power plants.

Chart 8 shows projected capital costs, a range and an average, in \$/Kw, for coal and nuclear power plants. Coal plants without sulfur dioxide scrubbers would typically burn low sulfur western coal while plants with SO₂ scrubbers would typically burn high sulfur eastern coal. The chart shows that average estimated capital costs for a 1000 MWe plant, which typically provides power for a city of 750,000 people, for startup in 1985 are \$660 million for a coal plant without scrubbers, \$780 million

for a coal plant with scrubbers, and \$920 million for a LWR nuclear plant.

Chart 9 shows the capital cost breakdown for the nuclear power plant. Note that the nuclear reactor itself and the steam generator, that is the nuclear steam supply system, is costed at \$83 million or only 9% of the total \$920 million capital cost. Note that the escalation and interest during construction (IDC) accounts for almost half of the capital cost. Construction labor cost accounts for 15% of the capital costs. In the last 10 years, power plant capital costs have increased drastically with nuclear power plant capital costs going up by almost a factor of 5 from about \$200/Kw in 1965 to the current projected \$920/Kw. The bulk of this increase, however, has been associated with escalation and interest during construction and with construction labor costs and therefore, with inflation and interest rates. All power plants whether they be coal, nuclear, geothermal or solar are affected by these factors. Nuclear plants tend to be relatively more affected by these factors than coal plants because of their relatively higher initial capital cost and the longer construction time resulting from licensing requirements.

Chart 10 shows a breakdown of the projected nuclear fuel cycle costs for 1985. These costs include the mining and milling of the uranium ore, conversion of the ore to uranium hexafluoride (UF₆), enrichment of the uranium to about 3% in U-235, fabrication of the fuel elements, shipping and chemical reprocessing of the spent, or used, fuel, shipping and disposal of the wastes, and a credit for recovered plutonium and uranium fuel during reprocessing. The cost of the uranium ore in 1985 is estimated in the chart at \$45/lb, which is nearly six times the cost of uranium ore in 1972. Note that the cost of the uranium ore and the enrichment

process constitute the bulk of the nuclear fuel cycle cost. Reprocessing, shipping, and waste disposal constitute only 7% of the cost showing the relative insensitivity of nuclear fuel cycle cost to reprocessing and waste disposal costs. Actually, these later costs are essentially recovered through the credit assigned to the recovered usable uranium fuel. The total fuel cycle cost is estimated at 0.81 ¢/Kwhr or 1.08 ¢/Kwhr when levelized over a 10 year period. The 0.81 compares to a current nuclear fuel cycle cost of 0.35 ¢/Kwhr as was shown on Chart 6.

Chart 11 shows coal fuel costs for coal delivered to the plant, as burned in 1975, and projected levelized coal prices for 1985 assuming either a 6% or 8% yearly escalation rate. Coal prices are given for coal mined in different regions in the country and for two hauling distances for western coal showing the sensitivity of delivered coal prices to the transportation distance. We will assume the 6% escalation case or a little more than doubling in coal prices over the next 10 years.

Using the average plant capital cost figures and the nuclear fuel cycle and coal fuel costs just discussed, we can estimate electric power generation costs for 1985 plant startup for nuclear plants and for coal plants in various regions of the country. We will assume a 15% annual fixed charge on capital cost and a 65% plant capacity factor (Chart 12). The bottom part of the chart shows the capital financing cost for nuclear plants and for coal plants in various parts of the country. Capital financing charges for nuclear plants are estimated 2.4 ¢/Kwhr. For northeastern, eastern and central regions coal plants burning high sulfur coal and requiring scrubbers, the capital financing cost is estimated at 2.0 ¢/Kwhr. For western region coal plants burning low sulfur coal and requiring no scrubbers, the capital financing cost is estimated at 1.7 ¢/Kwhr.

The fuel costs are shown above the capital financing costs reflecting the regional dependence of coal prices and the effect of hauling distance to the plant. Note again the relatively higher contribution of coal fuel costs as opposed to the nuclear fuel costs, to the total power generation cost. The operation and maintenance cost is shown on top of the chart reflecting the relatively higher O&M cost for plants with SO₂ scrubbers. The chart shows projected bus-bar costs ranging from 2.9 ¢/Kwhr for a coal plant in the western region located relatively close to the coal mine, to 5.6 ¢/Kwhr for a coal plant in the northeast. Recall that current bus-bar costs averaged over the country are 1.75 ¢/Kwhr for coal and 1.23 ¢/Kwhr for nuclear. The chart would indicate that nuclear power, through the next 10-15 years at least, is more economical than coal-fired generation in most parts of the country with the exception of coal plants burning low-sulfur coal and located near the coal mine.

A similar type of analysis has recently been published by the Edison Electric Institute (EEI), which is a research oriented principal association of the nation's investor-owned electric utility companies based on data collected from individual utilities (Chart 13). The results of the EEI study are shown on this chart showing projected fuel and total electrical power generation costs for nuclear and coal-fired plants in different regions of the country. The EEI study is even more favorable to nuclear power than our own showing an economic advantage of nuclear power over coal in most areas of the country.

To give you a feeling for the sensitivity of our projected bus-bar costs to the underlying assumptions, I have computed for a nuclear plant and a central U.S. coal plant the projected bus-bar costs under varying conditions (Chart 14). Shown are the effects on both the coal and nuclear

bus-bar costs of a 20% increase in capital cost, of an increase in financing charge from 15% annual to 17% annual, of changes in plant capacity factor from 0.65 to 0.55 and from 0.65 to 0.75, and of a doubling in fuel costs. Note that under certain conditions the coal plant becomes competitive with or more economic than the nuclear plant, while under other conditions the economic advantage of the nuclear plant is enhanced. The conclusion to be drawn is that it is essential for a utility company, before it purchases a power plant, to make a detailed economic analysis of current and anticipated conditions in its service region in order to select the type of power plant that is expected to generate electrical power at the lowest cost to the consumer.

We have also estimated the power generation costs in the year 1990 for other than coal or nuclear LWR plants, namely geothermal, solar, nuclear breeder (LMFBR), and refuse or municipal solid waste as a supplemental fuel in coal-fired boilers. Since none of these systems are commercial today and since many of the systems have actually never been built before, bus-bar costs are even much more uncertain than projected coal or nuclear costs and should be viewed with a great deal of speculative sense (Chart 15). The chart shows that the use of refuse or solid waste as supplemental fuel is attractive economically. Geothermal energy, already in use in California, should be economically competitive in certain parts of the country, particularly where geothermal steam fields exist. The breeder costs represent the current design objective for the LMFBR showing it to be competitive with LWR's.

It is doubtful at this point that solar electric generation could compete economically with other sources of energy, at least not until the turn of the century. Note that the eventual mix of energy sources

will not be decided only by economics, but also through consideration of resource availability, environmental impact and public health, and the state of technology.

III. Heat

Let me now turn to a consideration of the cost of heat as a form of energy. I will limit my remarks to space and hot water heating and focus on the economics of solar heating relative to current energy sources, including natural gas, number 2 heating oil, and electric heating (Chart 16). This chart compares current ranges of energy costs for various heating options in dollars per million BTU (MBTU). A BTU is a basic energy unit and represents the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. An average household in the U.S. requires about 100 MBTU per year for space heating. Recall that natural gas prices are currently subject to federal regulation. The lower cost in the range of electric heating assumes the use of a heat pump. The solar heating costs are best estimates and reflect a representative range of collector costs and financing costs. The chart indicates that solar heating would be competitive with electric heating, at least in some parts of the country, but would not be competitive with natural gas or heating oil.

There is a fair deal of uncertainty in the solar heating costs again because of a lack of firm data and the absence of an established solar heating industry. I would like to briefly discuss the computation of solar heating costs using a very simple model (Chart 17). I have assumed the solar unit lasts 20 years with solar collectors covering an 800 ft.² area, supplying about 60 MBTU per year. The solar unit costs, given in

$\$/\text{ft.}^2$, include collector, storage, distribution and back-up equipment. Unit costs at $\$5/\text{ft.}^2$ are about as low as anyone is willing to state publicly while $\$15/\text{ft.}^2$ represents the higher range of cost estimates currently published in the literature. I have assumed financing of the solar unit at an interest rate of $8\frac{1}{2}\%$ over a 7 year and 20 year period. While performing the computation, we called banks in Pittsburgh, said we wanted to install a solar heating unit and asked about loan possibilities. The banks told us they would consider this as a home improvement loan which typically today is seven years at $8\frac{1}{2}\%$. The 20 year loan would represent either installation of a solar unit in a new house under construction or in the case of an existing building, would imply some sort of government legislation on solar heating loans.

The results of the computation are shown in this chart (Chart 18), for the two types of loans and three unit costs. Note that the total capital cost ranges from \$4,000 to \$12,000. For comparison, a typical gas furnace costs around \$1,000. Energy costs are given in $\$/\text{MBTU}$ and $\$/\text{month}$ during the loan payback period and as total unit lifetime cost including interest. Maintenance and servicing costs have been neglected such that there would be eventually no cost after the payback period. Note the sensitivity of the heating costs to the unit costs and to the length of the loan payback period. With a 20 year loan, monthly heat bills are almost half those based on a 7 year loan during the payback period. However, total lifetime costs are about 60% higher with a 20 year loan period. As seen on the chart, the analysis leads to monthly bills ranging from \$65 to \$190 and lifetime costs ranging from about \$5,000 to \$25,000, depending on unit cost and loan period. To see the effect of government legislation giving rise to low interest loans for

solar heating equipment, we have computed the costs assuming a 5% interest loan. For a unit cost of $\$7.5/\text{ft.}^2$, the energy costs are $\$88.4/\text{month}$ and $\$7,000$ life cost for a 7 year loan and $\$39.6/\text{month}$ and $\$9,560$ life cost for a 20 year loan.

The solar heating costs discussed so far refer only to the cost of the solar unit. In most parts of the country and particularly in those regions where heating requirements are high in winter months, the solar radiation intensity is insufficient to meet the entire heat load and backup or supplemental equipment, such as a conventional furnace, is required. Solar heating economics must, therefore, properly account for the cost of the makeup heat source (Chart 19). Shown on this chart is the predicted performance of a solar heating unit for space and water heating in Madison, Wisconsin, for collector areas of 215 and 860 ft.^2 , for each month of the year. Units are million BTU's. The dashed line is the average monthly solar radiation in Madison. The top line in the histogram represents the total heating requirement for this particular house. The darkened portion of the histogram represents the contribution of the solar unit with the remainder to be provided by the auxiliary system. The larger collector area increases the contribution of the solar heating unit to the total heat load but also results in higher capital costs.

The net solar heating economics for this system has been calculated assuming a 20 year loan at 10% (Chart 20). The results are shown on this chart in terms of dollar savings per year relative to sole reliance on a conventional heating system. Negative dollar savings imply a net yearly cost increase. The economics are shown as a fraction of collector area for two collector costs, $\$5.5/\text{ft.}^2$ and $\$9.3/\text{ft.}^2$, and for two conventional

fuel costs, \$5/MBTU and \$15/MBTU. Note that the net dollar savings account for the cost of the auxiliary heating system. The two upper curves refer to conventional fuel at \$15/MBTU and the lower curves to conventional fuel at \$5/MBTU. The chart indicates that a solar heating unit would probably not be economically justifiable for conventional heating costs less than about \$5-\$6/MBTU. Again this implies solar heating to be competitive with electric heating. Note that there is an optimum collector area with larger areas leading to poorer economics because of the increased capital costs. Again these results would be sensitive to the loan conditions.

In summary, the relative economics of a solar heating system are dependent on an interplay between solar unit or collector costs, financing conditions, system design in terms of collector area, and solar heating performance as determined by local solar radiation characteristics, heating load and collector design and area.

IV. Chemical Fuels

I should like at this point to consider briefly chemical fuels economics. Because of the current federal regulations of natural gas prices, our heavy dependence on foreign oil, the unpredictability of foreign oil prices, and federal legislation affecting U.S. oil prices, I will not venture into a discussion of oil and gas economics. I should like, however, to give you an indication of the projected economics of synthetic fuels from coal. Here again, because of a lack of an established commercial industry and the uncertainty in coal prices, the costs are speculative (Chart 21). Shown on the chart are ranges of cost estimates for synthetic gas and synthetic liquid fuels from coal, compared to

current natural gas and crude oil prices in \$/MBTU. The chart generally shows the incentive to develop a synthetic fuels industry. Low BTU synthetic coal gas that would be fed to a power plant boiler is competitive with current fossil fuels. At current oil prices, synthetic coal liquid fuels, particularly those utilizing western coal, could be competitive. A major problem in developing a synthetic fuels industry, however, is related to the capital financing requirements for synthetic fuels facilities. Capital costs for currently envisioned facilities range between \$500 million and \$1 billion.

V. Research, Development and Demonstration Costs

Finally, I should like to briefly refer to the costs of developing new energy technologies; that is, the research, development and demonstration costs for which we, as taxpayers, eventually foot much of the bill (Chart 22). Shown on the chart are estimates of the development costs in billions of dollars, over a given time frame, needed to bring to a commercial status the technologies of synthetic coal fuels, the breeder, oil shale, solar electric, and fusion. Also shown for perspective, is the 1975 oil import bill for the U.S. Although these development costs by themselves appear high, note that the total cost of developing the breeder is equivalent to the cost of importing oil over a period of only about 5 months, while the estimated cost of developing a synthetic coal fuel industry is equivalent to the cost of oil imports over a period of about 8 months.

Since the end of the oil embargo, our dependence on foreign oil has continually increased such that in March of this year for the first time, we imported as much oil as we produced in the U.S. Since all the tech-

nologies shown on the chart would reduce our reliance on foreign oil imports, the economic incentives for and benefits to be accrued from our investments in energy research and develop are very high indeed.

Thank you for your attention.

480

ACKNOWLEDGMENT

I should like to gratefully acknowledge the support of Jack Penkrot in researching some of the economic data and in performing some of the solar heating economics calculations.

SELECTED REFERENCES

- "Energy Facts II", prepared for the Subcommittee on Energy Research, Development, and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, Ninety-Fourth Congress (August 1975).
- Leonard F.C. Reichle, "The Economics of Nuclear Power", presented to the New York Society of Security Analysts (August 27, 1975).
- Gordon R. Corey, "A Cost Comparison of Nuclear and Conventional Electric Generation", Public Utilities Fortnightly, p. 25, (April 22, 1976).
- "Nuclear Economics", Edison Electric Institute Press Release (April 1976).
- I. A. Forbes, "How to Calculate the Cost of Electricity", Energy Research Group, Framingham, Mass. (1975).
- Federal Energy Administration, Project Independence Blueprint: Solar Energy (November 1974).
- "Solar-Energy Prospects Not That Sunny", Electrical World, p. 60 (December 15, 1975).
- John A. Duffie and William A. Beckman, "Solar Heating and Cooling", Science, 191, 4223, p. 143 (16 January 1976).
- William A. Shurcliff, "Active-Type Solar Heating Systems for Houses: A Technology In Ferment", Bulletin of the Atomic Scientists, p. 30 (February 1976).
- E. L. Capener, "The Economics of Solar Energy", Chemtech, p. 190 (March 1976).
- Federal Energy Administration, Project Independence Blueprint: Synthetic Fuels from Coal (November 1974).
- R. W. Fri, Deputy Administrator, U. S. Energy Research and Development Administration, speech delivered to the New York Security Analysts, New York, N.Y. (February 17, 1976).

ENERGY SOURCES AND USES

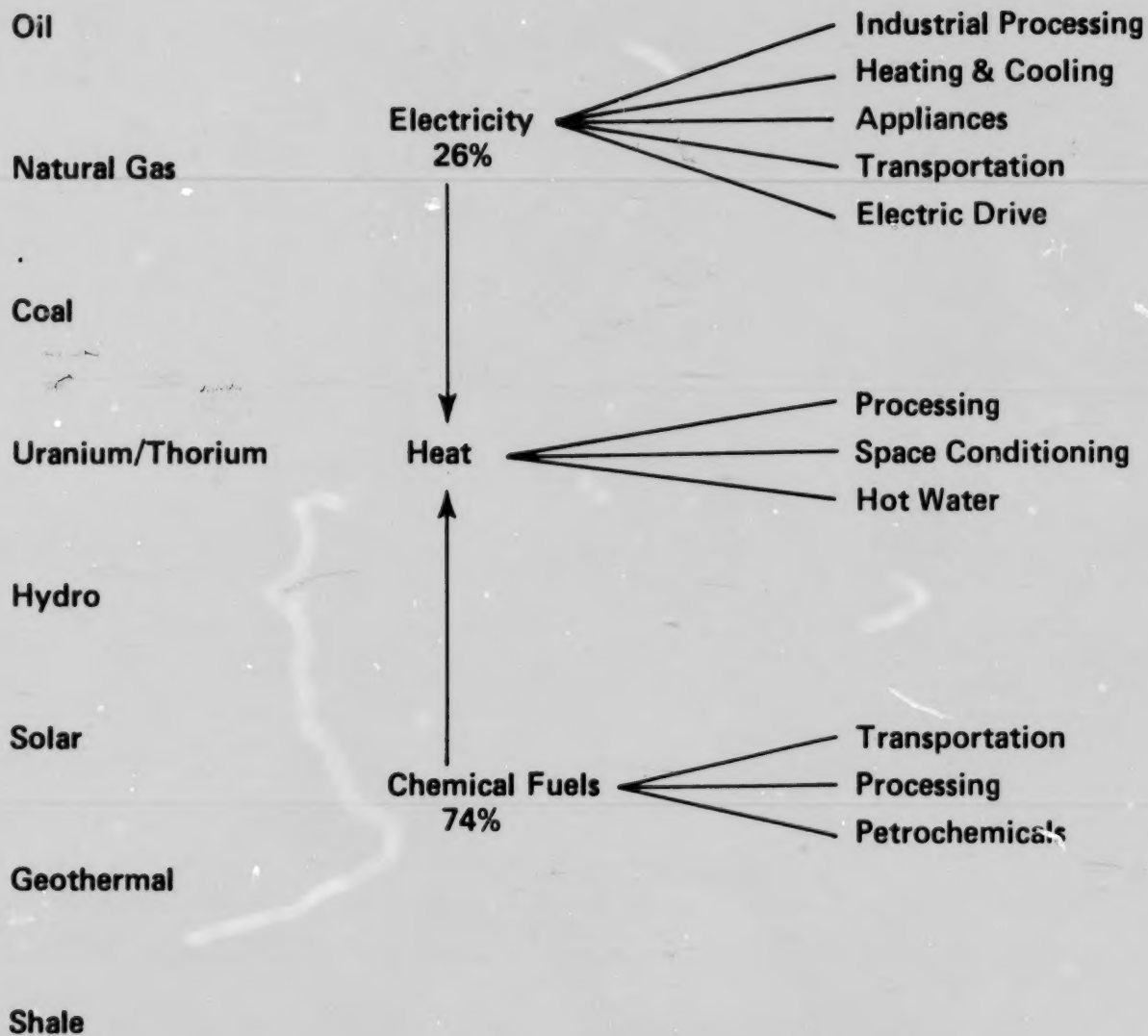


CHART 2

MONTHLY RESIDENTIAL ENERGY BILL

Poncelet Family

End Use	\$/Month
---------	----------

Electricity	15
Heating (Natural Gas)	27
Transportation (Gasoline)	50

ENERGY END USE COST BREAKDOWN

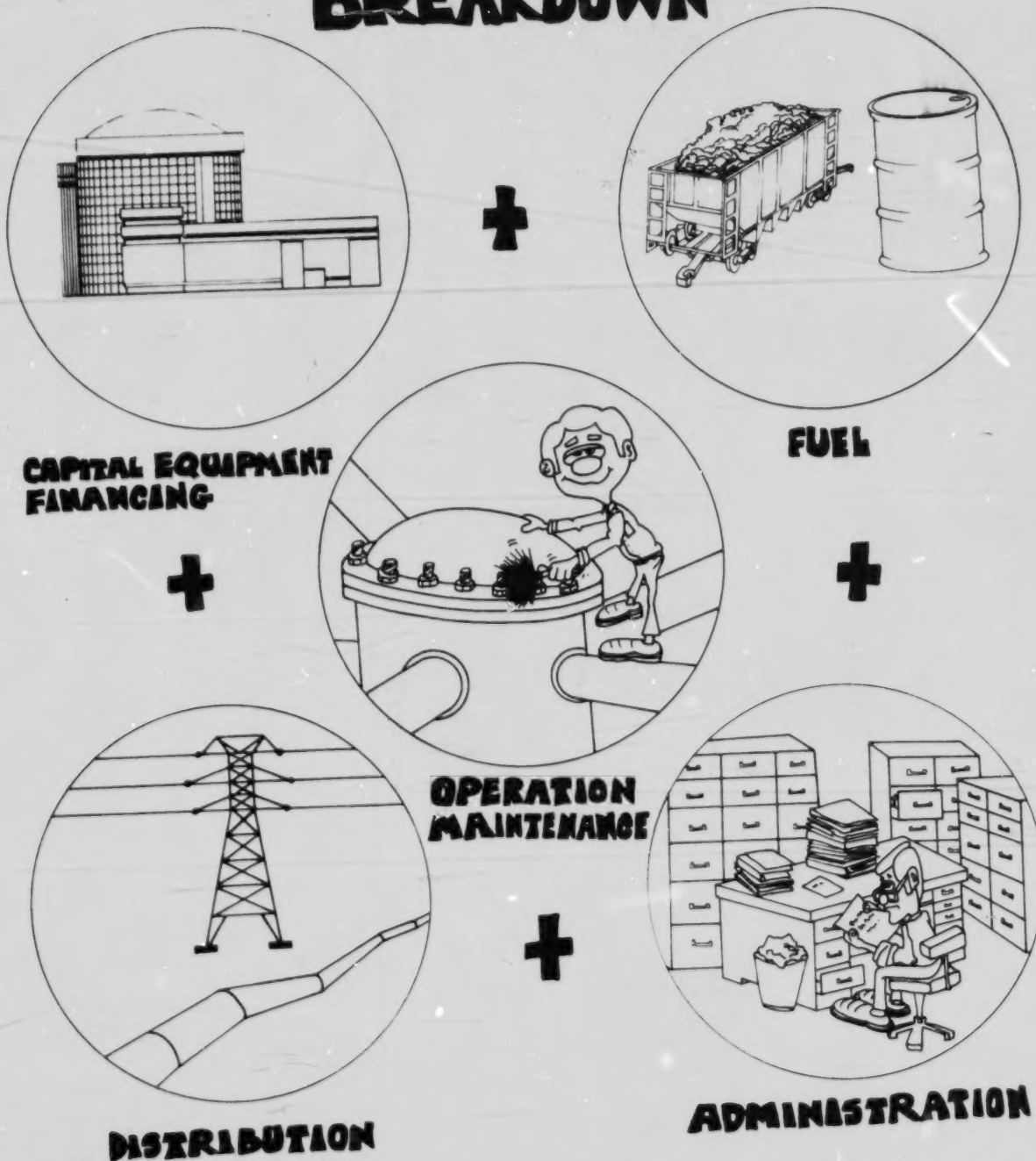
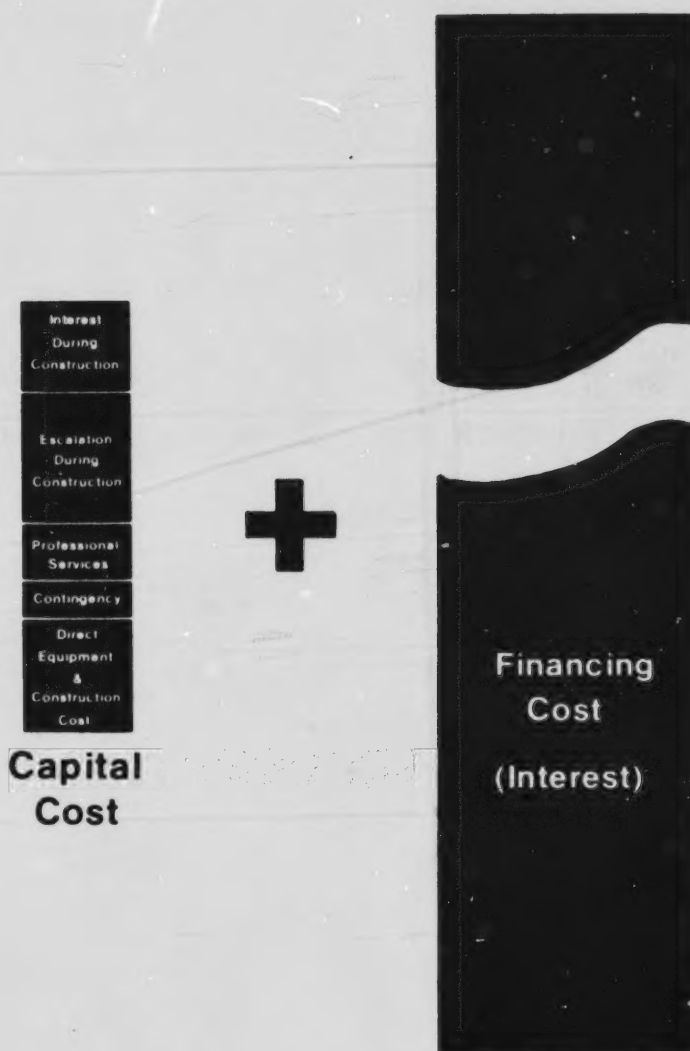


CHART 4

BREAKDOWN OF CAPITAL FINANCING COSTS



ELECTRICITY

487

LEVELIZED ELECTRIC POWER BUS-BAR COSTS

$$\frac{\$}{\text{Kwhr}} =$$

$$\frac{\text{Capital Cost (\$/Kw)} \times \text{Financing Charge (\%/Year)}}{8760 \text{ (Hours/Year)} \times \text{Capacity Factor}}$$

$$+ \text{Fuel Cost (\$/Kwhr)}$$

$$+ \frac{\text{O\&M Cost (\$/Kw-Year)}}{8760 \text{ (Hours/Year)} \times \text{Capacity Factor}}$$

1975 AVERAGE U.S. ELECTRIC POWER COSTS

	Bus-Bar Cost (¢/Kwhr)		
	Oil	Coal	Nuclear
Capital & O&M	1.26	0.73	0.88
Fuel	2.09	1.02	0.35
Total	3.35	1.75	1.23
Family of Four* \$ /Month	60.30	31.50	22.14

*2700 Kwhr/Person-Year
Bus-Bar Cost = 50% of End-Use Cost

SENSITIVITY OF ELECTRIC POWER COSTS TO FUEL COSTS

	Oil	Coal	Nuclear
Bus-Bar Cost (¢/Kwhr)			
1975	3.35	1.75	1.23
If Double Fuel Cycle Cost	5.44	2.77	1.57
Family of Four (\$/Month)			
1975	60.30	31.50	22.14
If Double Fuel Cycle Cost	97.92	49.86	28.26

**PROJECTED POWER PLANT
CAPITAL COSTS
(1985 STARTUP)**

	Capital Cost (\$/Kw)	
	Range	Average
Coal Without SO ₂ Scrubbers	610-760	660
Coal With SO ₂ Scrubbers	650-850	780
Nuclear (LWR)	800-1031	920

CHART 9

NUCLEAR PLANT COST BREAKDOWN 1000 MW—1985 COMMERCIAL OPERATION

Cost Item	Percent	Millions of Dollars
Reactor Plant Equipment	9.0	83
Turbine Generator	5.0	45
Balance of Plant Equipment	7.0	64
Construction Materials and Structures	6.0	55
Construction Labor	15.0	140
Professional Services	6.0	55
Owner's Cost	1.0	9
Contingency	5.0	45
Escalation and IDC	46.0	424
Total	100%	920

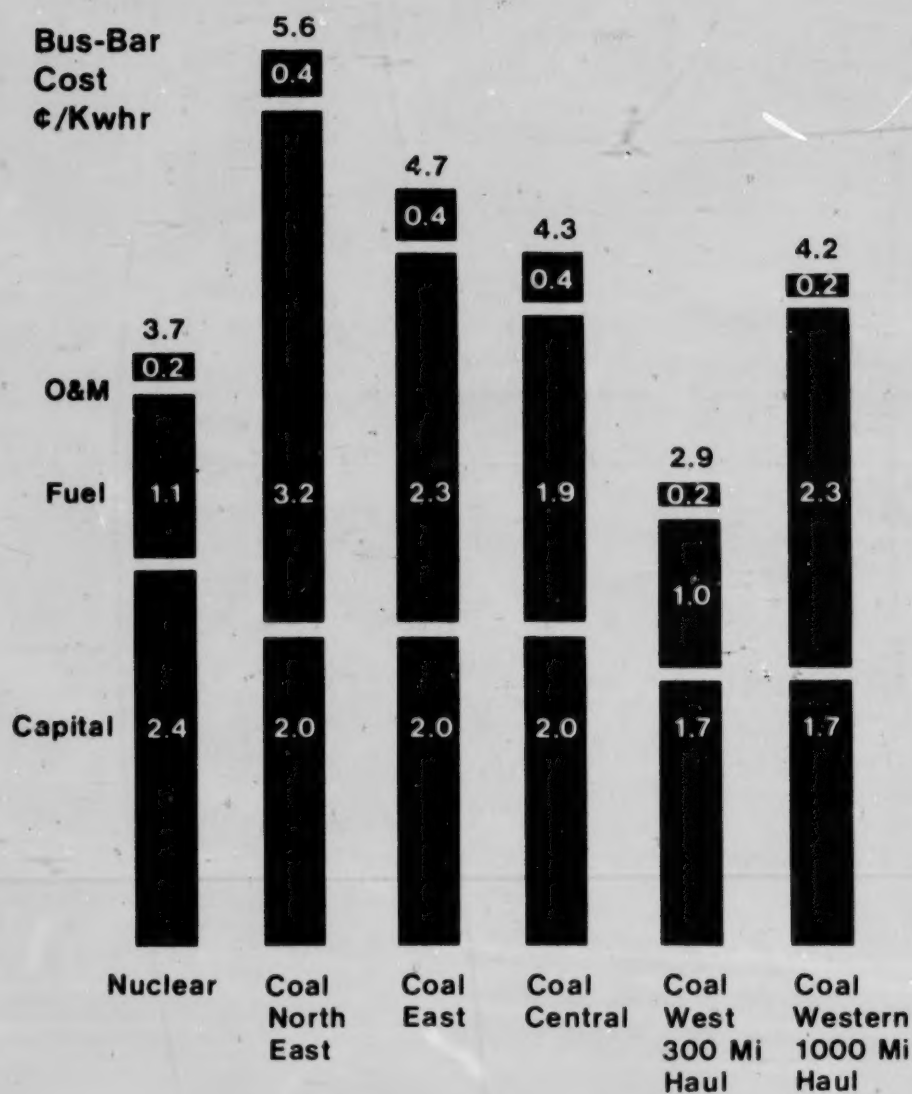
TYPICAL NUCLEAR FUEL CYCLE COST 1985

	Expected Rate	1985 Cost ¢/Kwhr	Percent of Total Cost
Mining & Milling	(\$ 45/lb)	0.512	63
Conversion to UF ₆	(\$ 5/kg)	0.020	3
Enrichment	(\$130/SMU)	0.294	36
Fabrication	(\$140/kg)	0.072	9
Reprocessing	(\$285/kg)	0.060	7
Shipping & Waste Disposal			
Pu Credit	(\$ 34/gm)	-0.077	-9
Uranium Credit		-0.071	-9
Sub Total		0.810	100
Carrying Charges		0.270	
Total		1.080	

PROJECTED LEVELIZED COAL PRICES
(¢ /MMBTU)

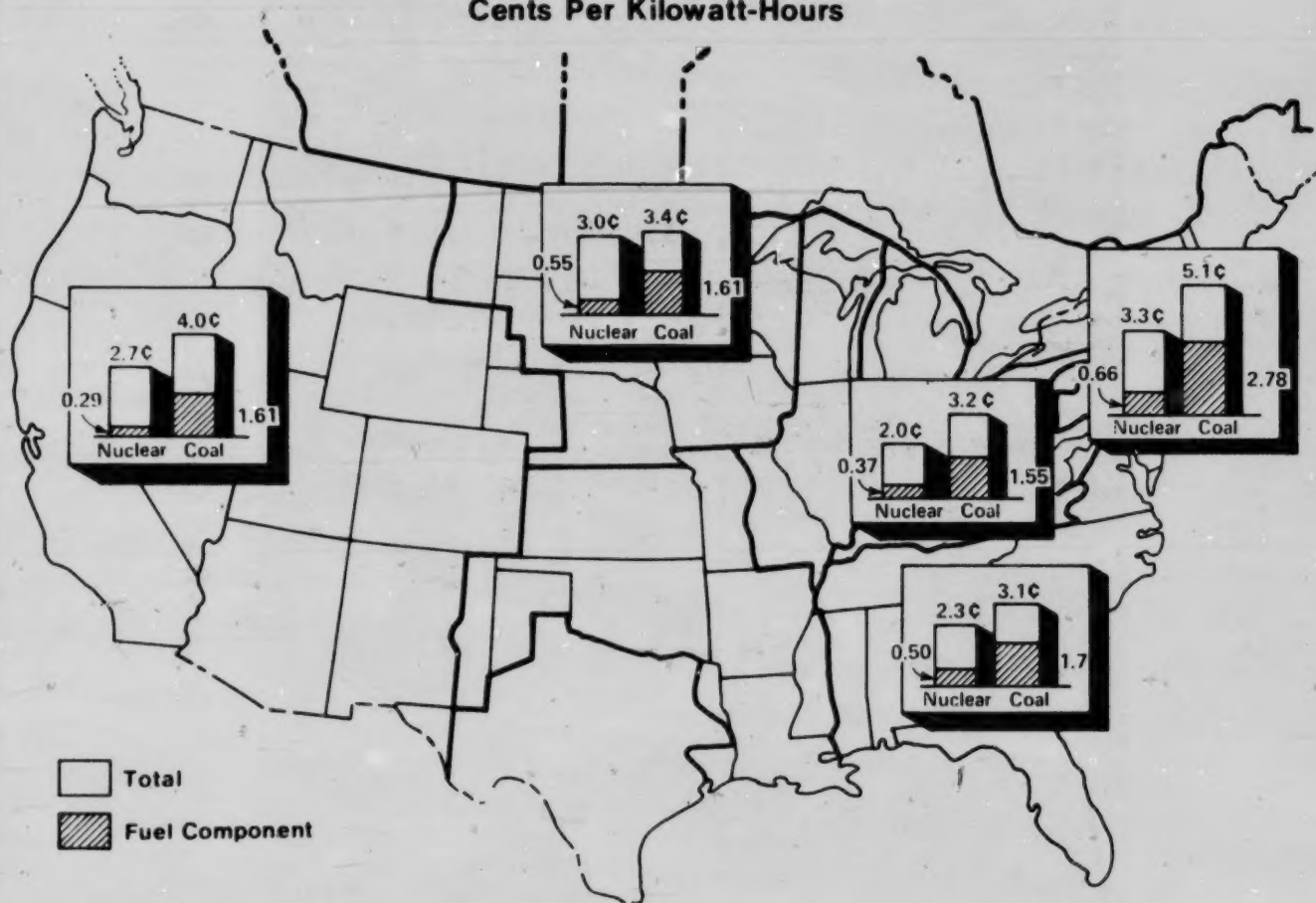
	As Burned Mid 1975	6% Esc. Mid 1985	8% Esc. Mid 1985
Northeast	\$1.35	\$3.20	\$4.30
East	0.95	2.30	3.00
Central	0.80	1.95	2.55
West (300 mi Haul)	0.45	1.10	1.45
Western Coal (1000 mi Haul)	1.00	2.40	3.20

PROJECTED ELECTRIC POWER GENERATION COSTS (1985 STARTUP)



EDISON ELECTRIC INSTITUTE NUCLEAR AND COAL ELECTRIC POWER COSTS (1980-1988 STARTUP)

Cents Per Kilowatt-Hours



**SENSITIVITY OF
PROJECTED POWER COSTS
(1985 STARTUP)**

	Bus-Bar Costs (¢ /Kwhr)	
	Coal	Nuclear
Base (Central US)	4.35	3.70
20% Increase in Capital Cost	4.77	4.19
Financing Charge 15% to 17%	4.63	4.03
Capacity Factor 0.65 to 0.55	4.73	4.14
Capacity Factor 0.65 to 0.75	4.08	3.38
Double Fuel Cycle Cost	6.25	4.78

**ESTIMATED ELECTRICAL
POWER GENERATION COSTS
FOR VARIOUS ENERGY SOURCES**

Power Generation Cost,
¢/Kwhr (Year 1990)

Coal	4.35
Nuclear (LWR)	3.70
Refuse Eastern Coal	4.80
Western Coal	2.70
Geothermal Steam	5.20
Brine	6.30
Hot Rock	7.40
Nuclear (LMFBR)	3.70
Solar Thermal	20.0
Thermal & Storage	40.7
Photovoltaic	106.2

HEAT

499

ENERGY COSTS FOR VARIOUS HEATING OPTIONS

\$/MBTU

Natural Gas	0.50 - 1.50
#2 Heating Oil	2.00 - 2.90
Electric	4.40 - 9.80
Solar	6.90 - 20.80

500

CALCULATING SOLAR HEATING COSTS

- Assume the unit lasts 20 years
- The unit is 800 ft² and supplies 60 MBTU per year -- 60% of needs of average household
- Units costs are given in \$/ft² and include collector, storage, distribution and back-up equipment. Look at \$5/ft², \$7.50/ft², \$15/ft²
- Assume 8-1/2% loan, paid monthly over 7 years or full 20 year life

ESTIMATED SOLAR HEATING COSTS

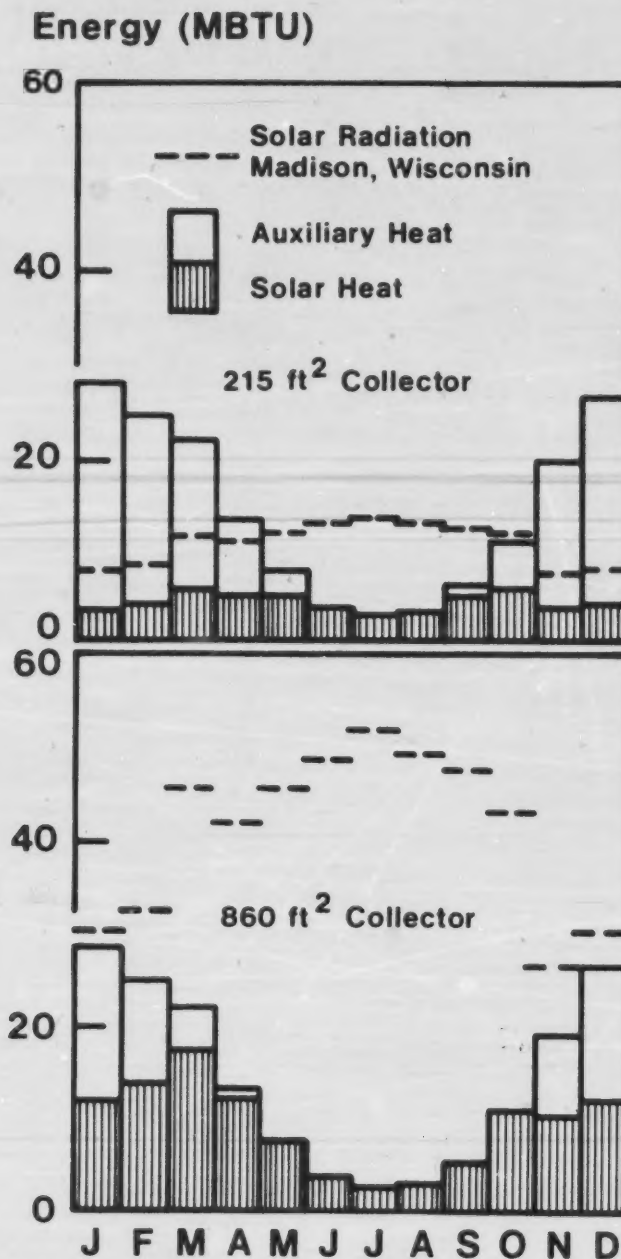
8-1/2% for 7 Years

\$ / ft ²	Unit Cost	Energy Cost During Payback Period		Life Cost (\$)
	Capital Cost (\$)	\$ / MBTU	\$ / Month	Including Interest
5.0	4,000	12.7	63.3	5,321
7.5	6,000	19.0	95.0	7,982
15.0	12,000	38.0	190.0	15,963

8-1/2% for 20 Years

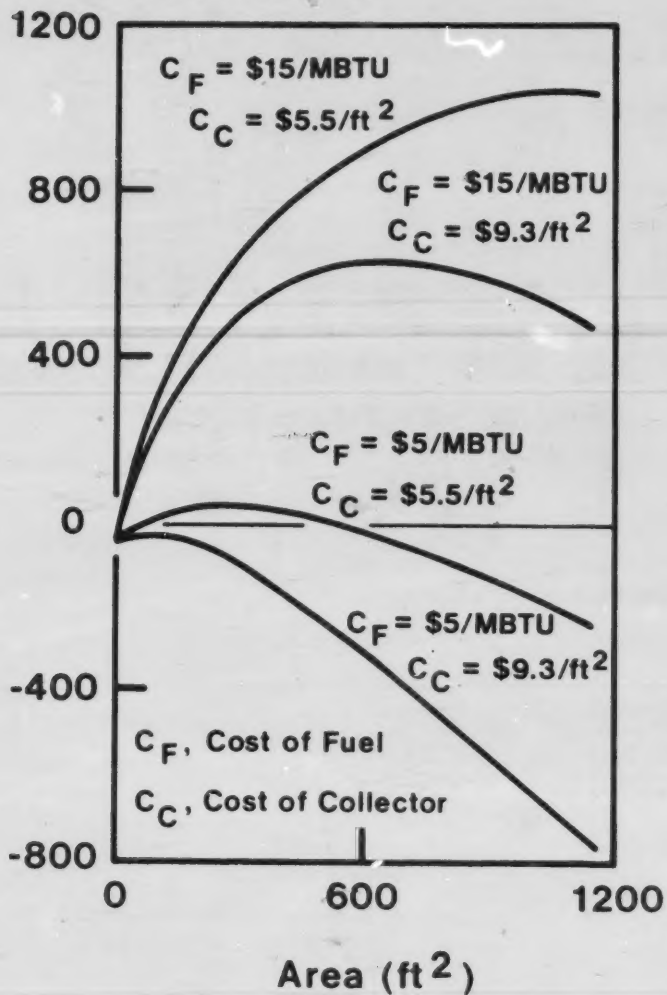
5.0	4,000	6.9	34.7	8,331
7.5	6,000	10.4	52.1	12,497
15.0	16,000	20.8	104.1	24,993

SOLAR HEATING PERFORMANCE (SPACE AND HOT WATER HEATING)



SOLAR HEATING ECONOMICS

Dollar Savings
per Year (Madison)



CHEMICAL FUELS

505

ESTIMATED SYNTHETIC CHEMICAL FUEL COSTS

\$/MBTU

● Natural Gas		0.50 - 1.50
● Synthetic Coal Gas		
■ Low BTU Utility Gas	Eastern Coal	1.20 - 1.80
	Western Coal	0.70 - 1.25
■ High BTU Pipeline Gas	Eastern Coal	2.60 - 3.40
	Western Coal	2.10 - 2.60
● Crude Oil		1.40 - 2.40
● Synthetic Coal		
■ Liquid Fuel	Eastern Coal	1.90 - 2.60
	Western Coal	1.40 - 2.10

TECHNOLOGY DEVELOPMENT COSTS

Technology	Time Frame	Cost (\$ Billion)
Synthetic Coal Fuels	1972 - 1985	18
LMFBR (Breeder)	1955 - 2000	12
Oil Shale	1976 - 1985	7
Solar Electric	1976 - 1985	26
Fusion	1950 - 2020	High
Oil Imports	1975	25

RELIGION, PHILOSOPHY AND ENERGY

By
DR. WILLIAM G. POLLARD

**Minister, Nuclear Physicist
Institute for Energy Analysis
Oak Ridge Associated Universities
Oak Ridge, Tennessee 37830**

508

-473-

RELIGION, PHILOSOPHY AND ENERGY

If you look at the title of the talk I'm to give, you can see it really covers a vast area. In the limited time available, I'm going to pick out only a few ideas that I feel need emphasis from a philosophic and human point of view.

I want to first tell you about a resource that seems to me of really fundamental significance to us in the United States. I might begin by pointing out our coal reserves so far as the future of energy in the United States is concerned. We are extremely well blessed compared to other parts of the world. The enormity of the reserves of coal we have--probably a good 500 billion tons of coal that could conceivably be mined. But perhaps less than half of that is recoverable without tearing up our national parks or highways or cities--somewhere between 150-300 billion tons which is an immense amount of energy. Of course, there are environmental problems in getting it out of the ground and burning it; problems you have considered in this meeting. But it's certainly a tremendous energy source that we have which Europe, Japan and other parts of the world do not. But we have an even larger resource which has been widely ignored.

Ever since late 1944, we've been enriching uranium in our gas diffusion plants. The tails of these plants have been stripped down from about 7/10 of a percent U-235, to about 2/10 of a percent. Those tails of depleted uranium have been stored in stainless steel drums. Each drum

contains 8,700 kilograms of uranium. Since late 1944 and early '45 when the Oak Ridge Diffusion Plant started running, we have now accumulated 20,000 of these cylinders. This is uranium already mined, processed and purified.

As soon as we have breeder reactors, we can convert all of that to plutonium fuel for electric power. Assuming that the uranium is cycled through the breeder 10 times and that there is a 1-2% loss at each pass, 70% of that depleted uranium can be converted to plutonium and provide energy in breeder reactors. Without any further mining and very little further process, that is an immense energy resource. The amount of electricity you can generate with it is the same as you could get from 450 billion tons of coal. It probably exceeds our total recoverable coal reserves. It is equivalent to 1,700 billion barrels of oil and that's probably the total recoverable petroleum in the earth's crust. We know of reserves totaling 600 billion barrels. If we assume 1,100 additional billion barrels still to be discovered, then the uranium we already have in hand is equivalent to that maximum total reserve of petroleum in the earth. It seems to me this is a tremendous blessing and that it gives much greater impetus to the development of breeder reactors because without the breeder reactor we can't use it; it's a worthless reserve. It's got to be converted into a fissionable form before we can get the energy out of it. Philosophically, even religiously speaking, knowing of the energy crisis that we're in, what kind of responsibility and obligation do we have to utilize such a providential windfall as that? I'll just leave that question with you.

Of course, there are problems in using it and we have to weigh those problems as carefully and objectively as we can. One of the problems

that's advanced is that if we utilize this reserve at anything like its potential, it means generating an immense amount of plutonium which could be made into bombs. So, there's the great concern as to how we can generate electricity with this immense reserve of fuel without increasing the dreadful problem of nuclear warfare. If, in another 50 years, there are breeder reactors all over the world producing plutonium, how do we live in a world in which plutonium is that abundant? This problem of the proliferation of nuclear weapons is certainly a serious one. However, there are two aspects that need to be emphasized.

First, there's already a great deal of plutonium unrelated to the generation of electricity. The United States has 30,000 war heads on our Minute-Man missiles and our Poseidon submarines--7,000 of them in Europe. This represents several hundred tons of plutonium already produced in production reactors at Hanford and Savannah River that have nothing to do with generating electricity. I don't know how much plutonium the Soviet Union has produced but probably an equal amount. Nuclear proliferation can and probably will go on as it has in the past independently of the development of breeder reactors and their deployment. In other words, we don't solve this dreadful problem of the nuclear holocaust by not satisfying human needs for energy with the fuel that's been given us. We're not going to stop proliferation by not developing breeder reactors.

Another important point is that producing atomic explosives is not very compatible with generating electricity. Power reactors strive for maximum burn-up in order to be economic. This requires leaving the bred plutonium in the reactor far longer than in production reactors. This allows it to absorb neutrons with a resultant mixture of isotopes rather

than pure plutonium-239 which is the good bomb material. About 30% of power plutonium is plutonium-240 and 241. The plutonium-240 is a source of neutrons from spontaneous fission which complicates triggering the bomb considerably, and the plutonium-241 has a short half life and so generates a lot of heat which requires cooling bombs stored for a long time. If it has reactor plutonium as your bomb material, you have got to cool them, you have got to remove that heat. In my judgment, any nation that is determined to develop nuclear weapons quite likely would prefer to get the plutonium not out of fast-breeder reactor reprocessing plants, but would instead build its own production reactor and so get good weapons grade plutonium. But this is an area of judgment.

We have to balance these problems. My guess is that whatever we do about breeder reactors, we are ultimately going to have to figure out how we live in a proliferated world in which practically every nation has nuclear weapons. It's a dreadful prospect, indeed, but I see no way of stopping it. So far we have lived in a partially-proliferated world without nuclear warfare. If in time every nation has them, then perhaps it is even a safer world than one in which only a few nations have nuclear weapons. I don't know. That is something that needs thinking about and considering. But the future of humanity on this planet does depend a great deal on the possibility of getting sufficient energy to maintain human civilization. By the time breeder reactors are really developed and deployed in another twenty or thirty years, our present reserve will have at least doubled. As long as we burn uranium-235 in light-water reactors, we are just going to add more and more of this depleted uranium to our reserves. We don't have to prospect for it or mine it or do anything.

I believe that man is intended to conquer his fear of nuclear energy sufficiently to use this providential energy resource for his basic needs in an energy hungry world. The whole problem of how we handle our fears and the risk of living is a deep philosophical and theological problem. What set man off from other species in his most primitive period was the use of fire. Using fire was very dangerous. And it is still a great danger. But man didn't turn away from it simply because it involved risks and dangers. I don't know that we are intended to ever devise a risk-free existence. In order to attain our ultimate potential, we've got to utilize dangerous things. The important thing is not to be overcome by what are really pathological fears.

I want to turn now to the way we handle the whole problem of radiation. We live in a sea of radiation and not only man but all of life always has. For one thing, when the solar system was formed it was formed out of debris of probably several supernova explosions which generated an immense amount of radioactive waste. The earth and all the other planets are loaded with radioactive waste. Much of the original radioactivity has long since decayed away. Since the solar system was formed 4.5 billion years ago, almost no radioactivities with half lives less than a half-billion years are left in the earth, but all of them with half lives of a billion years or longer are still around-- notably, uranium, thorium and potassium-40. It is this radioactive waste buried in the earth's crust that is responsible for volcanoes and tectonic activity, for continental drift, and for many of the features of the earth's crust. When we utilize our uranium resource in breeder reactors, we will necessarily generate more radioactive wastes. There is no way of avoiding that. Ultimately, we have got to dispose of these

wastes deep in the earth. But when we do, it is clear that we will not be adding something foreign to the earth. Although initially more concentrated, our man generated radioactive waste will never amount to more than a minute portion of that already there. Ultimately, the waste decays to levels that are of the same order as rich pitchblend ores. If some future generation digs into them without knowing what they are, they are not going into something that we haven't dug into unsuspectingly when we have mined radioactive ores.

There is a perspective on this problem that is very important in evaluating the question of radioactive waste disposal. The buried wastes in the form of ceramic glass-like cylinders would be dangerous to dig out and bring up to the surface for 300 years after their original burial. That, of course, is a dreadfully long time as human civilizations and cultures go. During that period, the strontium and cesium, which are gamma emitters would certainly be dangerous if anybody got down to these glass cylinders. But after that, what's left is plutonium and americium and other transuranic alpha matters which a newspaper is sufficient to shield. Many of the concerns that are expressed, it seems to me, simply bear no very good relationship to the reality of the situation.

The same is true about radiation in general. Here it seems to me very important that we distinguish what we know from what is speculation. This is rarely done. As Dr. Cosgrove was telling you this morning, experiments carried out with mice and other animals involve radiation doses of 50 to 500 rem and above. Doses of much less than 50 rem would require excessively large numbers of animals for statistically significant cancer induction or genetic effects. Here the unit rem for radiation dose, short for roentgen-equivalent-man, has been adjusted so that doses from beta rays

or neutrons are equivalent in their effects in animals or man to gamma ray doses. As a result of twenty years of such animal studies on a large scale, we know with some confidence what the effects of doses of radiation between 50 and 500 rem are statistically in mice and other animals.

The most that we know about the effect of radiation on man comes from what was called the Atomic Bomb Casualty Commission but has just recently been renamed the Radiation Effects Research Foundation, a non-profit foundation supported half by Japan and half by the U.S. This Commission early identified those who had been in the vicinity and the dose that each of these survivors received from where they were when the explosions at Hiroshima and Nagasaki, and has been following them clinically since 1947. We know that those who received dosages at the time of the bomb blast of 100 rem or more, some of them up to 400-500 rem, have recently begun showing a higher incidence of various clinical abnormalities than the rest of the population that weren't so exposed. For one effect, those people who received higher exposures are now developing lenticular opacity more frequently than in normal Japanese people not so exposed. That is one of the effects of receiving radiation exposure. The exposed group also show a higher incidence of thyroid carcinoma (although curiously so far only at autopsy), and leukemia. Those are the main things observed. Just recently, the ones that received the largest doses are now, thirty years later, beginning to develop breast and lung cancer possibly more frequently than unexposed individuals. So, we know that large doses of radiation can lead to some of these things. But the effects are still statistical. The majority of the survivors continue to show no clinically observable abnormalities.

We know that people who have smoked cigarettes heavily, a couple of packs a day, have a much higher chance of getting lung cancer than non-smokers. But we also know people who have smoked many years and are in their 90s and show no sign of lung cancer. It is the same with the Japanese survivors.

If we are talking about doses of 50 rem and higher, then we are talking in an area in which we have data and observation. But much of the current nuclear concern has to do with doses in the very much smaller levels of natural radiation exposure which average a tenth of a rem per year from radioactivity in the earth and cosmic radiation. But that is quite variable. People in Denver get a good two to three times that because of the altitude and the nature of the soil and earth there. There are some parts of the country, such as New Orleans, where you get less, only about a twentieth of a rem per year. But whether that causes any cancer or any other problem, we have no idea, no way of determining. Even for a lifetime of exposure, this is a hundredth of the radiation dosage on which we have any data.

Yet, even in the Rasmussen report when they calculate the hazards of a large-scale nuclear accident in which the radioactive core of the reactor somehow gets spread out over the landscape, they calculate the incidence of cancer for areas of contamination that go down to a twentieth of a rem annually in three years. How do they do it? Well, they have various formulas that extrapolate from 50 rem down to 0.05 rem and that is a terrific extrapolation. But these figures of the number of cancers resulting from very low levels of radiation are stated as though they were scientific and that, it seems to me, is irresponsible. Quite wrong. We ought to indicate where our knowledge, our experimental verified know-

ledge ceases, and where we are being purely speculative. Because for practically all of the calculations in the Rasmussen report of radiation effect, the number of cancers produced and that sort of thing, at least 90% or more are speculative. We don't really know whether it would produce any cancer at all. And they talk about genetic effects. Well, we can produce mutations in mice. That's been done at Oak Ridge, a very vast genetic experiment, but not with much less than 50 rem. Mutation rate increases cease to be detectable below doses of that amount. Among the Japanese survivors of Hiroshima and Nagasaki, even going now into the second generation, there is no evidence of any increase in genetic abnormalities over the population that wasn't exposed. Maybe if we follow their offspring for ten generations 100 or 200 years from now, we will begin to see some detectable genetic effects. Mice are followed for ten generations in these genetic experiments. Maybe it hasn't been long enough. But in thirty years and going into the second generation, there is nothing that you can see genetically. So to calculate genetic effects for 0.5 to 1.0 rem per year which is way below anything conceivably measurable and to print it and tabulate it as though you knew what you were talking about, is just irresponsible.

The way in which this is done is to assume a linear relationship extrapolated far beyond observations on which we have any data at all. It is all right to do that as a matter of caution; for example, for workers around a reactor or around radioactivity in hospitals, working around x-rays, etc., we ought to set standards of radiation exposure. First of all, keep them as low as is practical but apart from that it is all right to use these linear extrapolations, it seems to me, even though there is no way of verifying them but simply as a matter of

caution for the protection of workers. But to extend such caution to the point where you appear to know that you would increase the incidence of cancer with these small doses in the general public is just stating things in a way that is completely confusing.

I am basically concerned with the whole energy problem and the ways in which it involves human evaluation, our values, our judgment. I don't think we serve the best interests of humanity, the best interests of the future of human civilization, by pathological fears that have been grossly exaggerated. There is something about radiation that seems far worse to people in general than other environmental problems. We don't worry near as much about chemicals in the atmosphere and water and in the environment that are carcinogenic and which, in small amounts, might or might not lead to cancer. But when it's radiation, there is a terrific psychological reaction. It is something like when electricity was introduced early in this century; there were people who were terrified of the idea of electricity. I think radiation carries with it a sort of deep psychological fear that sets it apart from all other environmental hazards. But my plea is that we be perfectly clear about evaluating the dangers. Where we have to deal with any kind of environmental hazard that is way below the level at which we can make reliable scientific measurements, my preference is to say, well, if you are not exposing yourself to more than the normal variations mankind has always lived with, then I personally can't get excited about it. If my children moved to Denver and I knew they were getting three times as much radiation all the time the rest of their lives as I am getting in Oak Ridge, I wouldn't get too upset about it. It might increase the probability of their acquiring cancer but that increase is so minute that it really is unde-

tectable. I don't think it is dangerous to live in Denver. As I say, at levels that low, when you are talking about what mankind has been accommodating itself to all along, then I think no public concern should be expressed. And yet concerns are expressed, even by some scientists, about the danger of a 0.005 rem per year increase in the background radiation. Well that, it seems to me, is just plain pathological fear. It can never be resolved scientifically by any conceivable experiment.

NUCLEAR STUDIES IN FINE ARTS AND ARCHEOLOGY

By
DR. GARMAN HARBOTTLE

**Fine Arts and Archeological Research
Brookhaven National Laboratory
Building 555
Upton, New York 11973**

NUCLEAR STUDIES IN FINE ARTS AND ARCHEOLOGY

Thank you very much, John. Let me begin by saying what a pleasure it is for me to be here this afternoon to speak to all of you and give you a little relief and a little entertainment, perhaps a little intellectual entertainment or what one can do with atomic energy that has nothing to do with electricity or the generation of nuclear power, and consequently, is non-controversial. Wait a minute, I take that back. It is controversial to archeologists, which is another form of controversy, but that is "ivory tower" so it really does not count. In this conference, we have perhaps not kept clearly in mind that atomic energy, in addition to bringing the blessings of unlimited electric power at a certain cost, has a very great impact on our intellectual studies, our studies in the field of pure science, in chemistry, physics; in fact, atomic energy was important in these fields long before anyone dreamed that it could be used to generate power.

I want to report on a program on studies in the field of fine arts and archeology involving nuclear techniques. This work is being carried out in the Chemistry Department, Brookhaven National Laboratory, by my colleague Dr. Ed Sayre, who began the study about twenty years ago, and myself. Now, let me just parenthetically ask a question which may be in your minds and that is, why should ERDA, a government funding agency, concern itself with archeology and fine arts? Well, the purpose of Brookhaven Laboratory was to study all the ways in which atomic energy

could be used to improve our knowledge. Not merely our knowledge of power generation, not our knowledge of biology, but just knowledge in general. And through the years we have engaged in a number of academic projects which seem to have no practical influence, no practical results. However, it is interesting that many of these in the end turn out to have practical results and the work which we have done on the application of neutron activation analysis to archeological materials, principally pottery, ceramics from ancient civilizations--it turns out has sharpened up our focus in the application of these techniques to the life sciences, for example, pollution problems and other environmental studies.

At this very moment at Brookhaven, we have two Coast Guard cadets who are training this summer in the identification of oil-slick residues from oil that has been dumped in the Atlantic Ocean and has washed up on our beaches. They are going to attempt to identify the origin of these oil slicks and find the ship that they came from so that the Coast Guard can rush out, capture the ship that dumped the oil and fine the captain a quarter of a million dollars, which is what he will have to pay. So there is a fall-out from studies which are purely academic, a kind of fall-out into studies which are eminently practical and very, very desirable to carry on in their own regard.

Later this afternoon, Dr. Nelson is going to tell you about the application of some of these techniques to criminology and I am sure this will be very much in continuation of what I have been saying and you will see again a very fine practical application of this type of study.

I had said in my abstract that I was going to talk about different kinds of applications of nuclear techniques to ceramics but since the

abstract was written the turquoise work has developed so rapidly that I am just dying to talk to someone about it. We have so many new results that I thought I would give a general survey and then tell you about our work in pre-Columbian turquoise and use it as an example to show how we apply nuclear techniques in archeology.

I want to speak first about turquoise in history. Turquoise has been known for a long time. In Egypt we find objects made of turquoise from the first dynasty right down to the 20th dynasty, roughly 3000-1000 B.C. and these turquoises were brought from workings in the Sinai Desert. In 77 A.D., the great writer Pliny devoted a whole chapter to turquoise which he called "callais" and I'll read you a short quotation from it. He says, "the callais is like lapis lazuli in color, only paler. It more closely resembles the tint of water near the seashore in appearance." And I think this is a very good description. The Persians had famous mines of turquoise at Nishapur. These were already known in the year 130 A.D. to writers like Galenus. In the Middle Ages, it was thought that turquoise would preserve your eyesight from harmful accidents. It was also thought by Arabian and Medieval scholars to induce hilarity. I think one can be hilarious sometimes when he sees the price of turquoise jewelry, even today. It was also thought, and I think this is important for Arizonians, to protect you against the sting of scorpions. And finally, kings felt it would protect them against death in any form whatever. This explains why you find so few kings wearing turquoise buried in their tombs. In the 13th Century, turquoise was mentioned by Marco Polo. And coming up to Shakespeare, I don't know how many of you are familiar with the scene in "The Merchant of Venice," Act III, where Shylock has learned that his daughter Jessica

has eloped with a Christian and has more or less cleaned out his house, taken the credit cards, and all the rest of it along with her, and his friend who has run into Jessica in a distant city tells Shylock that Jessica has traded his ring that she took along with her for a monkey. And Shylock says, "Out upon her. It was my turquoise. I had it from Leah (his wife) when I was a bachelor. I would not have given it for a wilderness of monkies," which I think is a delightful way to describe the great value that was placed on turquoise.

When the Spanish conquistadores came to the New World, they were familiar, then, with turquoise. They had wide experience of it in Europe but they were totally unprepared for the lavish use of it which they found in Mexico as they landed. Let me turn now, for a moment, to the story of the conquest of Mexico because it is with this conquest and with the arrival of Cortez that I want to begin my story of our studies of turquoise. The year 1519 marked an extraordinary event in human history. It was a confrontation between two utterly different societies which up until then had now known each other except by the most distant rumors--really were basically totally ignorant of one another's existence. Montezuma II had been on the throne from 1502. He was an introspective king. He has been likened to Hadrian. He was not a purely militaristic figure, but a philosopher and poet. He had had some bad things happen in his reign which were in the nature of portents. Ten years earlier, before the Spaniards arrived in 1519, there had been bad signs, there had been a comet, like a tongue of fire, it was said, showering the light of the dawn. There had been mysterious fires take place in the temples in Mexico City, there had been floods. But most startling of all, there had been an episode in which some fisher folk had caught a crane feeding

in the marshes and this crane, when it was brought to Montezuma, was found to have a mirror in its head. When Montezuma looked in the mirror, he could see the night sky even though it was full daylight outside. He could see the stars in the sky in this mirror. And looking again, he could see a distant plain, people were moving across it, spread out in ranks, coming forward in great haste. They made war upon each other and rode upon the backs of animals that resembled deer. This was certainly a very frightening portent and the king of Texcoco, who was his friend, carried out a ceremonial ball game with Montezuma, won the ball game, and then forecast that the Empire of Mexico would be destroyed. What had happened had been the arrival of the expedition of Grijalva in 1518 that preceded Cortez' landing and if we may have the first of the large slides, we will see the city of Tulum (Slide #1) on the eastern coast of Yucatan which must have been one of the sights that the first Spanish expedition saw as they came along. Now let us have the next large slide, please, of Mexico (Slide #2). You can see, although it is not marked, Tulum would be here on the east coast--the Grijalva expedition came around, got as far as the area of Cintla and Comocalco then, perhaps a little farther, and turned back. The story of this expedition was told to Montezuma. He had very good advice, very good intelligence, and what we now must do is examine a bit more of his character. He was in many ways a prisoner of his own history, his own religion, and particularly, the Toltec traditions. He imagined himself descended from the priest-king of the Toltecs, Quetzalcoatl, in a direct line. They carried on the idea of these traditions of the priestly descent and the thing that really, I think, was the worst for him was the meticulous detail which Toltec history had given about the next arrival, the ultimate arrival,

the return of the god, Quetzalcoatl. Quetzalcoatl was said to return with blond hair, with a beard, would return "in a mountain sailing on the sea" and that furthermore, his return would come in the year which translates "one reed" and this year was unfortunately 1519. There was an almost unbelievable series of coincidences that made Montezuma a prisoner of his own history.

Cortez finally arrived in 1519. Montezuma knew he was coming, had advance notice of this, and felt this had to be the god Quetzalcoatl returning and although he was terribly frightened, he thought, "I had better do the right thing; I had better take the god his accoutrements; I had better send him messages of our good will, welcoming him on his return to his own kingdom, but I must send him the most precious things that we have." What this slide will show you is what happened as expressed in the Florentine Codex (Slide #3). This event took place at the Jamapa River, about twelve miles south of the modern site of Veracruz. You can see in the upper picture the messengers from Montezuma bearing the gifts to Cortez. And you will see one of the messengers is carrying a necklace of jade of great value and carrying a sun made of gold. And in the next picture, below, is what happened. The messengers from Montezuma were thrown into irons--here are Cortez' men fastening iron chains on them, and you notice that Cortez already has the jade necklace on his neck by this time. He didn't waste any time in getting hold of that. The Spaniards kept the messengers there long enough to demonstrate to them the cannons and the horses, and then let them go back to Montezuma. It is very interesting to relate the messages that were carried back. The messengers told their emperor about the horses which they described as being like deer and how these deer, just as in the forecast, carried the

men on their backs. They also told them about the dogs which the Spaniards had along. The Mexicans, at this time, had only very small dogs which they raised for food. But the Spaniards had very large dogs. And the Mexicans said, "their dogs are enormous with flat ears and long, dangling tongues. The color of their eyes is a burning yellow. Their eyes flash fire and shoot off sparks. Their bellies are hollow, their flanks long and narrow, they are tireless and very powerful. They bound here and there panting with their tongues hanging out and they are spotted like an ocelot." Surely a very terrifying thing for Montezuma to hear. But the most terrifying of all was the description the ambassadors gave of the cannons that the Spaniards had in their ships. "The cannon shoots a thing like a ball, a ball of stone comes out of its entrails, it comes out shooting sparks and raining fire. If the cannon is aimed against a mountain, the mountain splits and cracks open. If it is aimed against a tree, it shatters the tree into splinters. This is a most unnatural sight, as if the tree had exploded from within." When Montezuma heard this report he was filled with terror and the chroniclers say, "it was as if his heart had fainted, as if it had shriveled, as if he were conquered by despair."

Now I want to show you some of the things that may have been brought by the ambassadors to Cortez from Montezuma. If you are in London and in Picadilly, as I am sure some of you have been, and you pass through the Burlington Arcade and you can get your wife by the shops that are there, you will emerge on the north side at Burlington Gardens and just close by will find the Ethnographic Collection of the British Museum. And there you will be able to see some of the objects which Montezuma sent to Cortez thinking that this was the god Quetzalcoatl returned.

This is the famous serpent mask, a mask of the god Quetzalcoatl, in the British Museum and I want now to tell you a little about the turquoise that is in it (Slide #4). The mask was described in the early days; let me read to you the words of Father Sahagun, who was one of our most important informants, "A mask worked in a mosaic of turquoise. This mask has a double and twisted snake worked in those same stones whose fold was on the projection of the nose, then the tail was parted from the head, and the head with part of the body went above one of the eyes so that it formed an eyebrow. The tail with a part of the body went over the other eye to form the other eyebrow. The mask was decked with a great lofty crown full of rich feathers, very long and beautiful." Now, when the messengers came to Cortez, they put this mask on him as being the appropriate recipient of it, the god Quetzalcoatl himself. Notice, please, that there is turquoise of several kinds and that the turquoise is sorted in colors so that one snake is formed of blue turquoise that forms this circle around the eye, then this fold comes around, goes underneath and comes around the bottom of the mouth on this side whereas the greenish turquoise forms the other serpent folding here, coming around this eye, passing under the other snake here.

And this brings up a point relevant to our use of the term turquoise. Turquoise is a chemical and has a chemical formula. But the archeologist and particularly the archeologist with whom I work, Professor Weigand, from the State University, Stony Brook, New York, uses the term turquoise to mean "cultural" turquoise. Turquoise could be any stone that is used culturally, in this sense. It could be a green stone such as a malachite, it could be a chrysocolla, or any of numerous other minerals. So, we must distinguish between cultural turquoise and chemical turquoise. It

is obvious that there is chemical turquoise on this mask but also perhaps cultural turquoise, some other green stones which are not the chemical turquoise at all. Note particularly up here a very interesting little recycled jewel. There is a little piece that does not make any sense in terms of the serpent mask but is apparently a turquoise jewel that was broken up and recycled when they made this mask.

This is one of the other pieces in the British Museum, a skull which represents the god Tezcatlipoca and can be almost positively identified as one of the pieces that was given to Cortez (Slide #5).

This is a mask of again possibly Quetzalcoatl or it may be the Sun God Tonatiuh and it is thought that could be the case because of the small lumps of turquoise set in the mask (Slide #6). This god is a god who had leprosy and threw himself into a fire and the blisters on his face may be what are represented by the small pieces of turquoise that are visible there.

The next slide shows two smaller objects (Slide #7). The mouth of this small animal which has turquoise and also the green stone, very possibly malachite mosaic work, the mouth has garnet put into it to represent the red tongue. Much of the mosaic is missing on this small piece, which is a cup-bearer. There is another slide of mosaic (Slide #8). However, the history of this piece is not so surely known. This is again Aztec mosaic although the twin-headed serpent was a very favorite Toltec attribute, as you can see in Uxmal on some of the buildings where they use the double-ended serpent very effectively.

This brings us then to the Spaniards' arrival in Mexico City and this, of course, was a moment of great importance in human history and brought the confrontation of these two societies to a climax and I

want to tell you of the impressions of the Spaniards as they entered Mexico City. Bernal Diaz writes very well--he was a soldier with Cortes and wrote afterwards in a very detailed fashion of his experiences. I would like to quote from him on his impressions as they marched into Mexico City, coming along the south side of Lake Chalco, crossing over on a causeway that is not shown on this modern map (Slide #9), and then coming along through Ixtapalapa, passing this great dike set up by one of the kings to give this side of Lake Texcoco fresh water and keep out the salt water on the other side. And finally, passing over this causeway into the city itself. Let me read how Bernal Diaz describes this scene and you can put on the next slide because it is the Spaniards' representation of what they saw (Slide #10).

"During the morning we arrived at a broad causeway and continued our march toward Ixtapalapa, and when we saw so many cities and villages built in the water, and other great towns on dry land, and that straight and level causeway going toward Mexico, we were amazed and said it was like the enchantments they tell of in the legend of Amadis, on account of the great towers and temples and buildings rising from the water, and all built of masonry. And some of our soldiers even asked whether the things that we saw were not a dream. It is not to be wondered at that I here write it down in this manner, for there is so much to think over that I do not know how to describe it, seeing things as we did that had never been heard of or seen before, not even dreamed about."

The Spaniards came in then, on the causeway, from Ixtapalapa arriving in what is now the center of the city near the Zocalo--the orientation is not quite what it is today, it is offset by a little--but this is the map that Cortez sent back to his head of state, Charles V, and used it to describe the City of Mexico itself. The dike which was set up across Lake Texcoco to separate the sweet water from the salt is shown here on the Spanish map. Also, the causeway leading toward Chapultepec, for

those of you who have been there, carried a fresh water supply through an aqueduct that passed across the lake and fed the City of Mexico itself. Mexico City, at that time, had about 300,000 people; this was roughly five times the size of the city of London, under Henry VIII, so it was very, very impressive to them. When the Spaniards arrived, they found, of course, that human sacrifice was in full swing and that the temples in the Zocalo carried abundant evidence of this. Since we have all read about the conquest of Mexico, we don't need to spend any more time on that. But I would like to spend just a moment to give you the feeling of the impact that all this had when they sent back to Europe objects like those you have seen.

We all know the name of the great Italian goldsmith, Benvenuto Cellini, and when he saw the magnificent work with gold and silver that came back from the New World, that Charles V had received from Cortez in Mexico, he cried out in admiration that he could not understand how the Mexican goldsmiths had been able to attain such a standard of perfection. Now this was a man who as a critic knew what he was talking about. Another artist in Europe who saw these pieces come back was the great German painter Albrecht Durer and he kept a diary during the 1520s in which he records a tantalizingly small segment of his response to these objects of which you have seen the pictures. I quote,

"I also saw the things that were brought to the king from the new land of gold, a sun entirely from gold, (you remember we saw a picture of that sun being handed to Cortez in the ship), a whole fathom wide, a moon entirely of silver, of equal size; likewise, two rooms of rare accoutrements, all manner of weapons, armor, bows, and arrows, wonderful arms, strange garments, all manner of wonderful things for many uses. These things are all so precious they are valued at 100,000 guilders and in all the days of my life I have seen nothing that has rejoiced my heart as these things, for I saw among

them strange and exquisitely worked objects and marveled at the subtle genius of the men in distant lands. The things I saw there I have no words to express."

Now one of the things that Albrecht Durer may well have seen was the skull of Tezcatlipoca, which I showed you, the inlaid skull from the British Museum.

I would like to discuss the extent of the use of turquoise in Mexico before the arrival of Columbus and Cortez and then to pose the question of its origin. In the period of the Teotihuacan civilization, which runs roughly from 200 A.D. up to 600-700 A.D., turquoise was already being used on a substantial scale. In the pre-classic period, which is very much earlier, there is only slight evidence of its use. But it really begins to be used extensively when you come to the period of Tula, that is the Toltec civilization (900-1200 A.D.) and then by the time of the Aztecs, there is apparently enormous use of turquoise in the center of Mexico. Please remember that the objects I showed you are a minute fraction of what was in existence at that time.

Where did the turquoise come from? We feel fairly sure that there are few turquoise sources in Mexico itself. There are one or two and they may even have been used aboriginally, but there is nothing like the amounts of turquoise that is necessary to explain this colossal utilization of it in the valley of Mexico. This point was recognized as early as 1858. There was a man called Bram Hertz who lived in Frankfurt, Germany, and was one of the owners of some of the pieces you saw illustrated which are now in the British Museum. He wrote a letter to the man who eventually gave the pieces to the British Museum explaining how he had come by them. And in it is a very interesting paragraph. I will

read it to you:

"I was requested by some gentleman to exhibit the aforesaid two articles (the skull and the first mask, the serpent mask) at the Royal Asiatic Society, which I did. Professor Wilson was in the chair who doubted them to be of Mexican origin, as he argued that no turquoise were found in Mexico. I replied that I was aware of that but that the Mexicans had communication with other countries who might have supplied the material for these articles."

If we read the great bible and encyclopedia of people who like turquoise, the volume by Pogue entitled The Turquoise, republished by the Rio Grande Press--it was originally a memoir of the National Academy of Sciences--Pogue states, "there are no important deposits of turquoise known in Mexico." He does mention one or two very small ones. But Pogue feels in discussing the turquoise the Spaniards found that the Aztecs were using, "It is almost certain that part of it at least was obtained through trade from the Cerrillos district of New Mexico." The Cerrillos mine is very close to Santa Fe. But there are also, in the southwest, many other mines which show strong archeological evidence of aboriginal mining activity. At Cerrillos this activity was on a colossal scale; tens of thousands of tons of rock were moved.

Now, I want to go into the technique of neutron activation analysis and how that could help us to solve this problem of whether Cerrillos or other southwestern U.S. turquoise may have been the sources of the turquoise that was being sent to Mexico in pre-Columbian times. There is a technique in neutron activation analysis which can be called fingerprinting. By the analysis, we establish the concentrations of many elements, trace elements, etc., in the turquoise. I am going to show you now exactly how we carry out these analyses and when we have found a pattern of trace elements, how we can use this to characterize the

source of turquoise or of pottery. Most of our work has been with pottery; we have a lot of experience to draw on because we have been analyzing archeological ceramics for close to twenty years. We have attempted to apply the same technique to turquoise drawn from many of these mines in this area, to the problem of characterization, the problem of finger-printing.

All right, how do we do neutron activation analysis? It is really quite simple. These slides will refer to pottery but the techniques are very similar for turquoise (Slide #11). We must grind or drill out a sample. We must package the sample for irradiation in the nuclear reactor and we put in with the samples standards, which are substances where we know the concentrations of the different elements we are going to analyze. Here is how we put the samples into the reactor (Slide #12). We use a pneumatic tube. They go into a rabbit, as the container is called, and the rabbit shoots into the center of the reactor through this pneumatic tube and, of course, can be returned to us the same way. Now, inside the reactor the samples are bombarded with neutrons which pass through the samples (Slide #13). A few of the neutrons, however, are caught in the different chemical elements that comprise the turquoise in this case because turquoise has all of these elements in it and many more. If you have, for example, scandium present, the scandium captures a neutron, becomes radioactive scandium; the radioactive scandium emits gamma rays of different energies which enable us to identify it as scandium. We count the sample after it comes back from the reactor (Slide #14). The samples are held up in front of a counter and the gamma rays are analyzed by a machine called the multi-channel analyser. And here is what you actually get out of this machine (Slide #15). You get a

gamma ray spectrum with a number of peaks on it and these different peaks then correspond to the different elements for which you are analyzing and which you have activated by neutrons in your sample. For example, here is one of the scandium peaks at 889.1 kilovolts. This tall peak is scandium. All we need to do is compare that scandium peak to a scandium peak in the standard and we, viola, have measured the amount of scandium in the turquoise. As you see, we can measure many elements; in fact, 15-20 elements in the turquoise. We next do some data processing by computer. But note that we come out at the bottom with a chemical profile of each sample and this chemical profile then is a set of concentrations of sodium, potassium, rubidium, cesium, scandium, etc., up to twenty odd elements in that particular turquoise and that profile characterizes, that is the finger-print, then by which we will recognize other samples of turquoise coming from that same mine as the one we have irradiated.

Now, what does one of these profiles look like? I do not have one of turquoise, but here is one of them from some pottery from Oaxaca which we analyzed a few years ago (Slide #16). You see that on one side there is a scale of concentrations in parts per million and the little cross mark indicates the concentration of sodium, potassium, cesium, etc. You can read off all of the elements yourself. The totality of this profile then gives us a picture of the chemical composition of that turquoise by which we can identify that turquoise as coming from that particular mine and, hopefully, from no other mine. It is the finger print, in other words.

Now I want to turn to the computer based process by which we can recognize samples having similar chemical compositions (Slide #17).

Here I have three coordinate axes defining three-dimensional space. Take a point b for instance. You see it characterized by x, y, and z values. On the slide, the coordinates are actually designated X_1 , X_2 and X_3 . And if these three coordinates were concentrations of chemical elements, let us say iron, scandium and sodium, then that point b would give us all three of those measurements. In other words, the point b characterizes, in that case, how much sodium, how much iron, and how much scandium there is in that particular sample. So, the point b then characterizes the analytical chemistry of that sample. Now, I must ask you to let your mind run past three-dimensional space into fifteen or twenty-dimensional space--let us say twenty-dimensional space. Let us set up this space hypothetically and the point b then in twenty-dimensional space would give us the total concentration of twenty different elements in the sample b. Well, a twenty-dimensional space is a little hard to visualize. Our minds don't like to go to more than three or maybe four or five if you are a science-fiction buff. But three dimensions are easy to visualize. What we have to do then is find points in twenty-dimensional space that are close together. I am going to show you how we do that.

This slide (Slide #18) shows us a calculation of what is called Euclidean distance, which is just the distance between two points, let us say points A and B in the previous slide. And this equation for A is nothing but the Pythagorean proposition in three dimensions. (In this slide the coordinates are X, Y and Z instead of X_1 , X_2 and X_3 .) And in twenty dimensions you can do exactly the same thing. You can set it up where you have twenty of these terms instead of three of them. So you can get the distance between points in twenty-dimensional space. Now,

if I have two turquoise samples that are chemically similar to each other in all elements, that distance is going to be small. If they are different from each other, that distance is going to be large. And all we have to know at this point is how to find the small distances, how to find the samples that cluster closely together.

All right, let us have the next large slide (Slide #19). This shows the technique we use called "cluster analysis". It is a computer oriented way of picking out the short distances first and we then link those samples together. For instance, here A and B are close together and we link them on this scale where the shortness of distance is greater the higher up you are and the farther down you get the greater the distance. And so you link first A and B together in cluster analysis, then you find out which ones link up next. Points C and D link up next. And so you link A-B here and you link A and B to C and D but you link it at a level which is a poorer match. You are matching not quite as well. And you continue doing this, linking up samples, and what you see emerge when you are all done is groups of samples that have relatively short distances to one another. In other words, these are groups of samples that are chemically similar to one another. And this plot you get at the bottom is called a dendrogram; it is a very nice way of showing in two dimensions the kind of clustering that you are getting in two dimensions here or in multi-dimensions. In twenty dimensions, you can make dendrograms that work perfectly well (I am going to show you one in a minute) that show you the clusters of chemically similar samples in any number of dimensions you want.

This is actually a dendrogram of pottery from the Aegean area (Slide #20), from Greece, and from the Middle East and in it you see

very clearly the emergence of groups of pottery sherds that have similar chemistry to each other. For example, here is a group that has very, very close ties to one another. But if I ask how close that group is to this group down here, then I have to follow these lines up to the point where I can get across. And that means that they tie only at this level up here which is very dissimilar, very unlike one another. Now, we have done this with the turquoise analyses and before I tell you the results, I would like to run through some of the small slides to show you where we get our samples.

This is the Cerrillos district of New Mexico which is one of our prime suspect areas for being a supplier of turquoise to Meso-America (Slide #21). The hill on the right, I believe, is Mt. Chalchihuitl and there are many, many mines that have been exploited in this area, although I understand it is fairly quiet today. In Mexico, one of the areas we've investigated does not produce turquoise; it produces a green stone that was used culturally. This cultural turquoise source is the Ejido Cardenas area in Zacatecos near the Chalchihuites archeological district. And in the area there are literally dozens of aboriginal mines. The next picture will have an adit entrance to one of these (Slide #22). My colleague, Phil Weigand, the archeologist, actually goes down in these holes along with innumerable scorpions, tarantulas and vampire bats, etc., and finds there remains of aboriginal mining activity and also brings out samples of the green cultural turquoise that we analyze.

This map shows some of the areas in which we have worked and some of the possible trade routes which we are investigating (Slide #23). We are looking at mines in this area of Colorado, Villa Grove, as well

as all through the American southwest. I wanted particularly to point out to you Casas Grandes which may have been an emporium on the turquoise trade route into Mexico. Guasave, the Chalchihuites district and La Quemada and, of course, ultimately Mexico City itself.

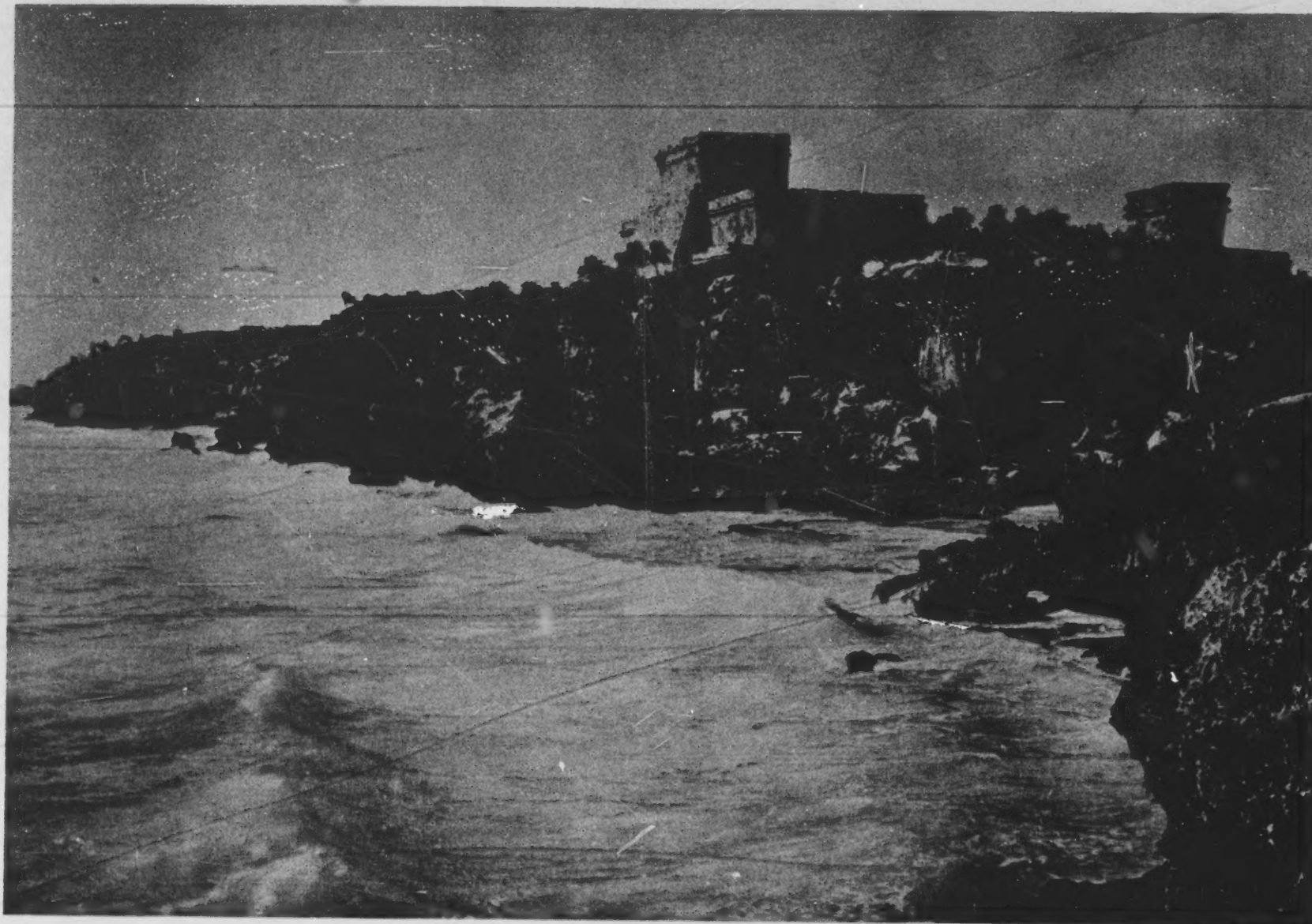
What have we done so far? So far, we have analyzed many, many turquoise samples from mining districts and have also analyzed a large number of artifacts from the Chalchihuites-La Quemada district, and from the American southwest. I want to talk briefly about the importance of Chaco Canyon. Chaco Canyon is a very interesting site in that it contains workshops for turquoise with incredible amounts of turquoise fragments found in them. Most of these are in the American Museum of Natural History. They have never even been counted but the minimum number is 50,000 pieces of turquoise that were found in or near Pueblo Bonito in Chaco Canyon. The maximum is probably something like one-half million pieces of turquoise. We have access to this material. We will be analyzing some selected pieces from it but the important thing, I think, is that Chaco Canyon was apparently one of the important processing centers though not a producing center.

Let me very briefly summarize what we know so far and I want to emphasize that this work is still in progress. You are not going to get any final answers but you are going to get some indications of what we know on the basis of our dendrograms that we have run of our turquoise analyses. The first thing we know is that there is no basic analytical problem, that the method works. The second thing we know is that different samples taken from the same mine cluster closely together. In other words, they have small distances and that is just exactly what you want. Thirdly, we know that mines within a given district tend to

cluster with each other though at a lower level than samples from within a given mine. In other words, we can finger print the district as well as finger printing the mine itself. We know that there is a clean separation between Mexican material and material coming from the American southwest. There is no problem, no possible confusion chemically between these two. We know that material which we got from La Quemada clusters with itself. And we have reason to suspect that material came from Cerrillos and we think we know which of the Cerrillos mines it came from. We can definitely exclude mines like Villa Grove, Morenci, and the O'Neill mine, which is also at Cerrillos, and the White Signal Mine. They cannot have been the suppliers of this La Quemada material. We know that some of the Pueblo Four sites in the Rio Grande Valley were also getting material from this same Cerrillos area, which is not surprising. They are very close by. Finally, we have one artifact fragment from Chetroketl which is in Chaco Canyon that is identical to one of the mines in the Cerrillos district. This is the first hard evidence that anyone has provided that the Cerrillos district was in fact feeding Chaco Canyon. The picture then is Chaco Canyon as a clearinghouse and a processing center for turquoise, probably from a number of mines including Cerrillos. This material was prepared in the form of mosaic blanks and shipped off to Mexico in vast quantities. How are we going to prove this? We now have material from Mexico. We have, in fact, turquoise mosaics from one of the Tezcatlipoca skulls, not the one you saw in the picture, but a similar one that was found in southern Mexico. We have a number of samples from the Monte Alban period, even from the Toltec period, from a number of sites in Mexico, which we are going to be analyzing in the months ahead. I think that the whole story is shaping

up extremely well. We see nothing so far to make us think that the Southwestern United States was not the supplier of the turquoise that eventually went into the pieces that you see in the British Museum today.

-507-



542

SLIDE #1

543



-508-

544

SLIDE #2

545



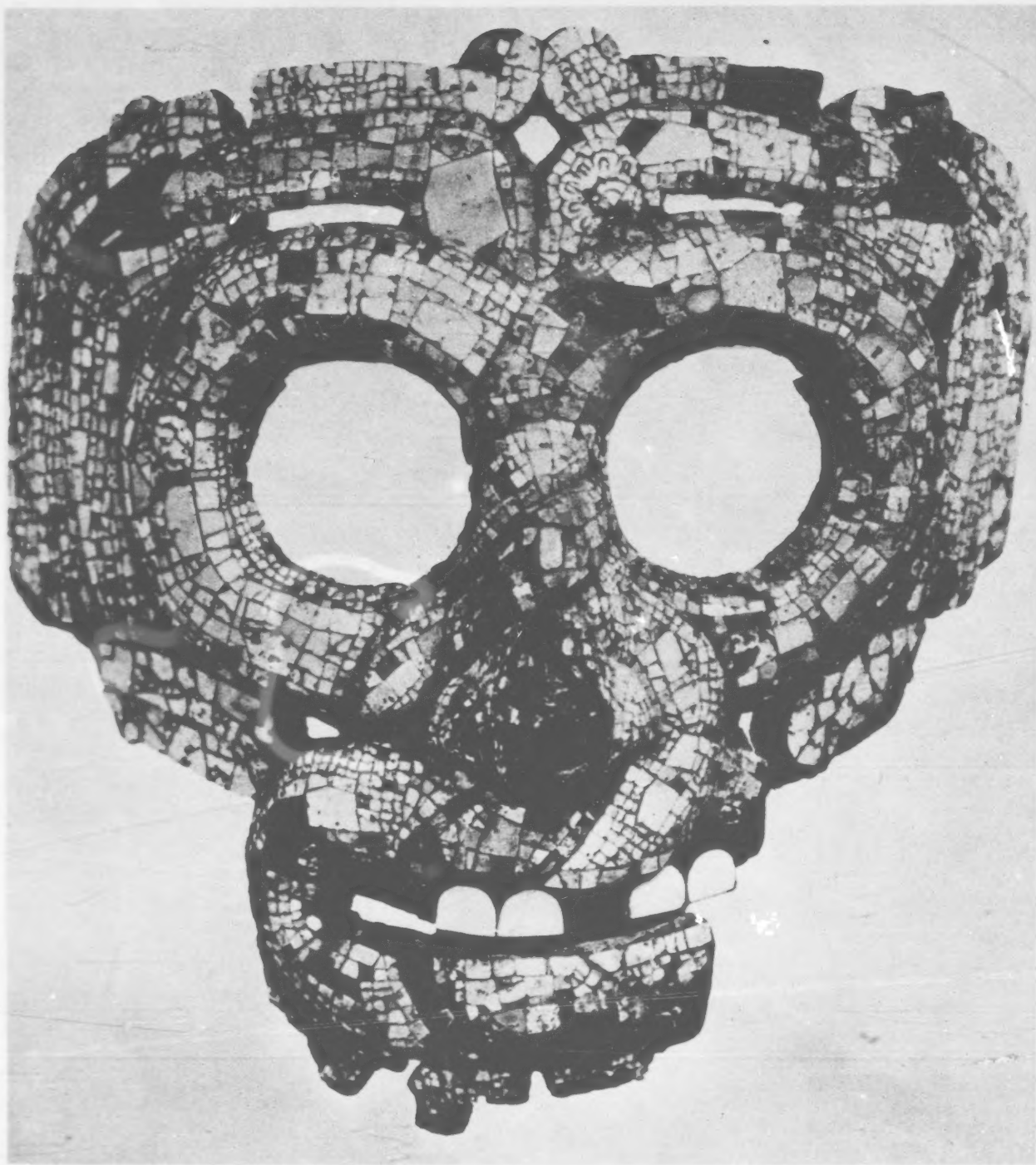
Messengers from Moctezuma bearing gifts
to Cortés
Florentine Codex



Messengers from Moctezuma thrown into
irons
Florentine Codex

SLIDE #3

-509-546



SLIDE #4

-510-517



SLIDE #5

-511-

548



SLIDE #6

-512- 549

-513-



550

220

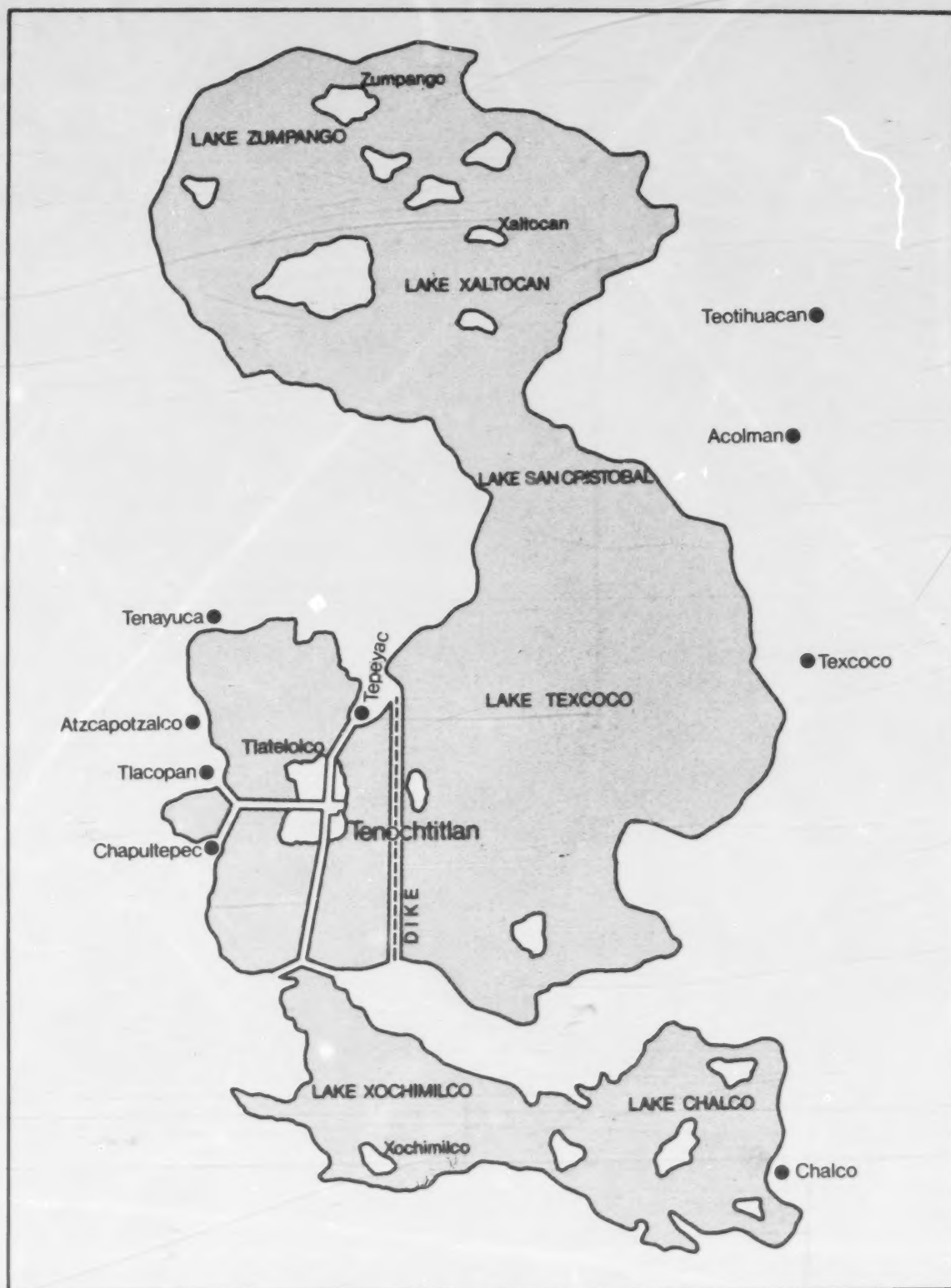


-514-

SLIDE #8

551

552



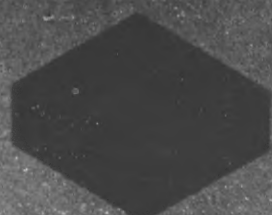
SLIDE #9

Tenochtitlan

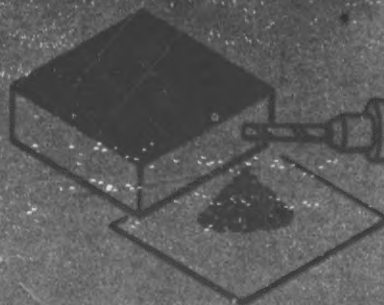
-515-

553

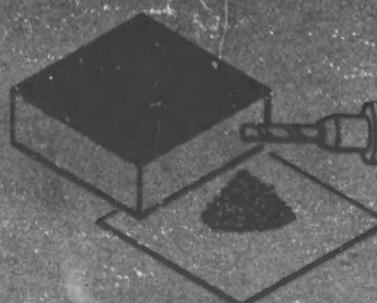
PREPARATION OF SAMPLE



SHERD



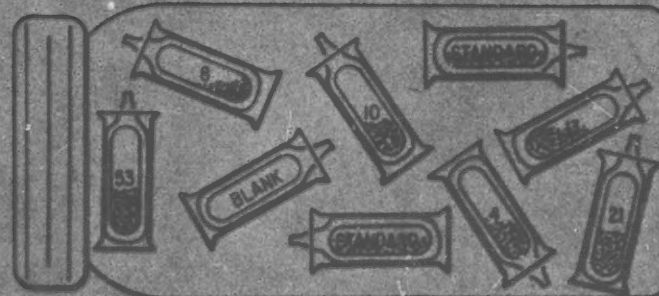
OUTER SURFACE
REMOVED



DRILLED

POWDER IS
DRIED TO A
CONSTANT
WEIGHT

40 MG IS WEIGHED OUT
INTO A TUBE OF QUARTZ,
SEALED AND LABELED



SAMPLES PLUS 6 STANDARDS
[GROUND ROCK OF KNOWN COMPOSITION AND
CONTAINING ALL ELEMENTS TO BE MEASURED]
SEALED IN A TUBE FOR IRRADIATION

-517-

-518-



557

SLIDE #12

558

IRRADIATION

519

REACTOR
SOURCE OF NEUTRONS



NEUTRONS PASS THROUGH
MOST SUBSTANCES

CO⁵⁹
COBALT

K⁴¹
POTASSIUM

SC⁴⁵
SCANDIUM

CO⁶⁰

K⁴²

SC⁴⁶

CO⁶⁰ 1332 KeV
1174 KeV

K⁴² 1524 KeV

SC⁴⁶ 1119 KeV
889 KeV



AFTER RADIOACTIVITY
DECAYS AWAY SAMPLES
ARE THE SAME AS
BEFORE IRRADIATION

INDIVIDUAL
ELEMENTS IN
EACH SAMPLE
ARE BOMBARDED
BY THE NEUTRONS

RADIOACTIVE
ISOTOPES
ARE FORMED

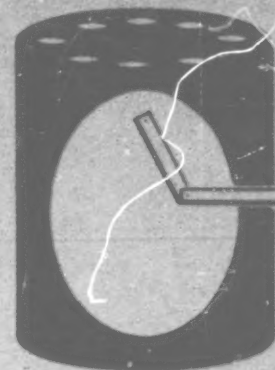
ISOTOPES EMIT
GAMMA RAYS AT
DIFFERENT ENERGY
LEVELS

SLIDE #13

COUNTING

-520-

SAMPLE HOLDER
AND
CHANGER



MOVES EACH SAMPLE
TO COUNTER FOR A
SET TIME LENGTH

COUNTER
LITHIUM-DRIFTED
GERMANIUM
CRYSTAL



REGISTERS
EACH RADIATION
REACHING CRYSTAL

AMPLIFIERS



MULTI-
ENERGY



CHANNEL
ANALYZERS

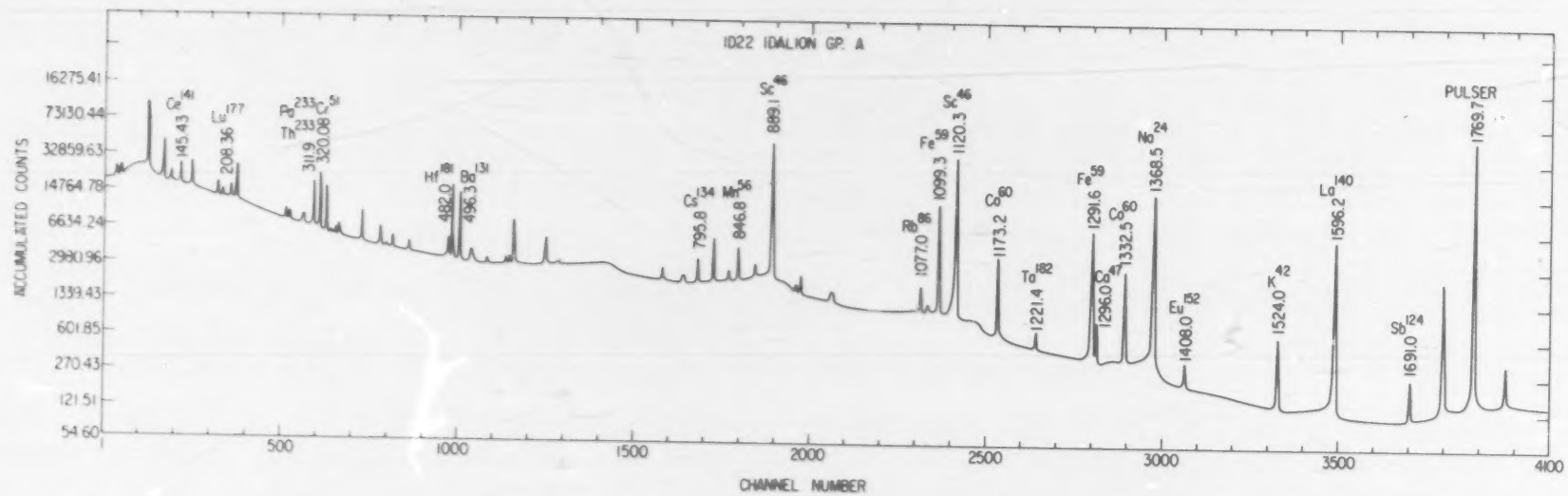
TAPE
RECORDER



TABULATES EACH COUNT BY
ENERGY LEVEL AND FEEDS TO
TAPE RECORDER THE SUMS OF
THE COUNTS AT EACH ENERGY
LEVEL FOR EACH SAMPLE

SLIDE #14

521



SLIDE #15

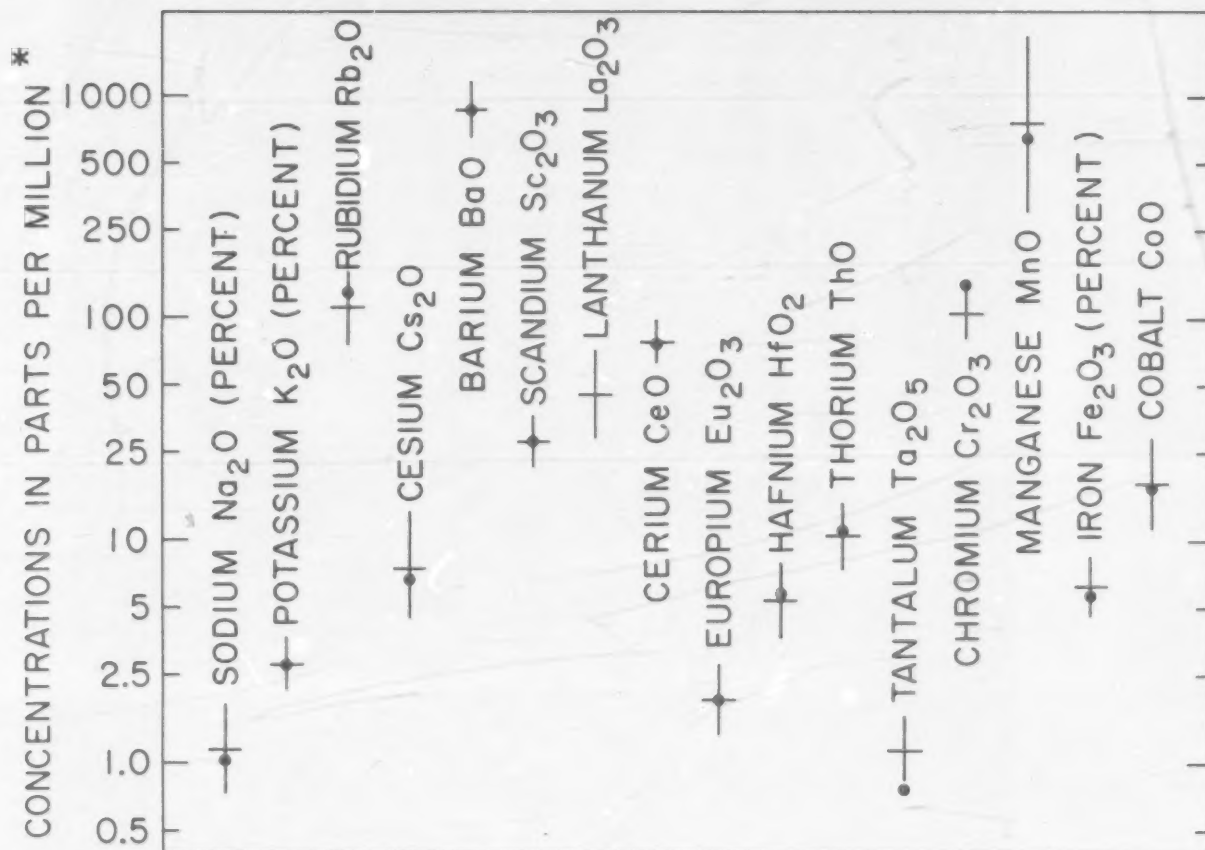
563

564

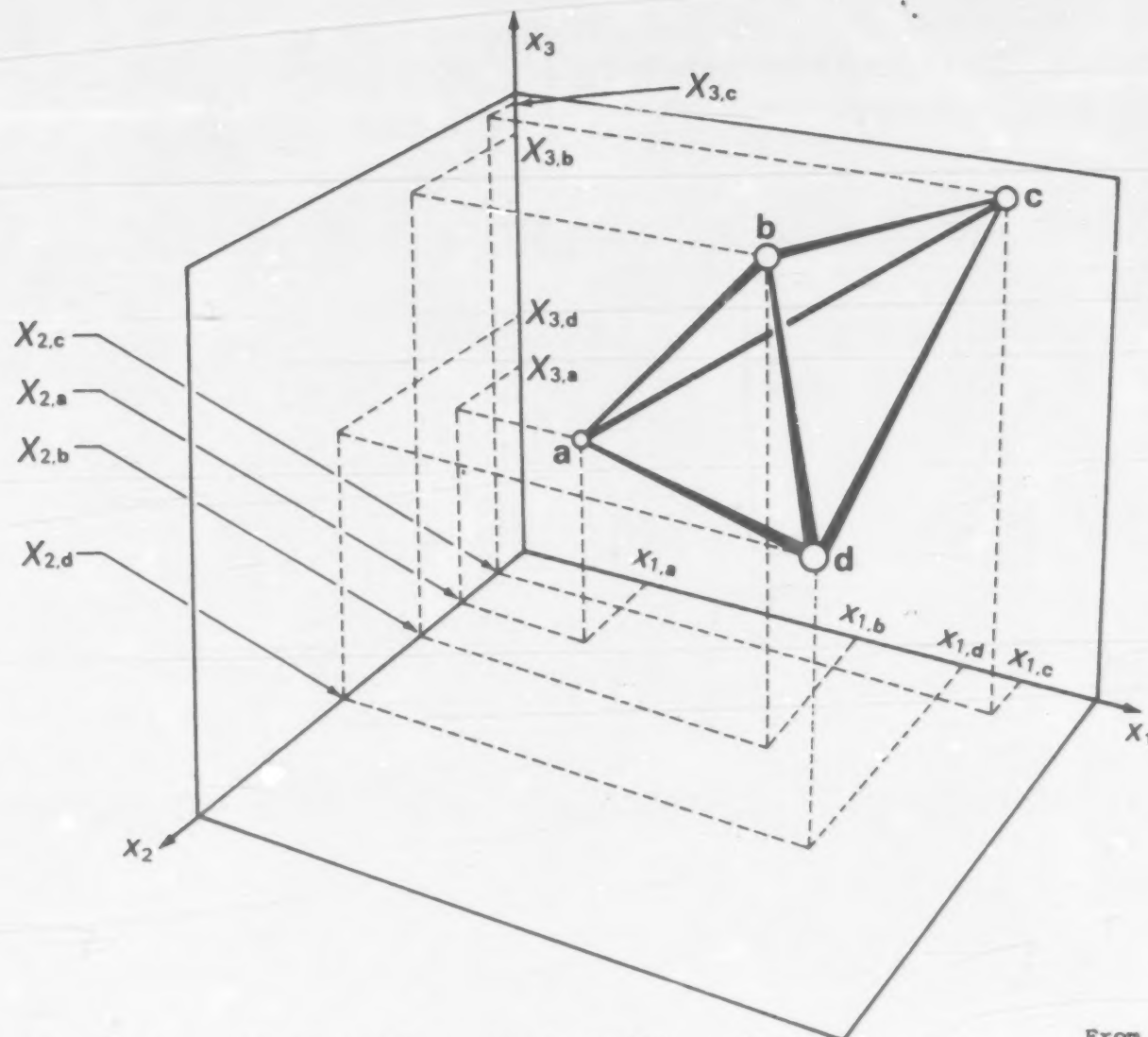
COMPARISON OF THE CONCENTRATIONS OF MANY OXIDES
IN ANCIENT POTTERY AND IN MODERN POTTERY AND CLAYS
FROM OAXACA

AVERAGE CONCENTRATIONS (—) AND 95 PERCENT CONFIDENCE
RANGES (|) OF TWENTY ANCIENT POTTERY SHERDS
CONCENTRATIONS (•) IN A MODERN OAXACAN CLAY

SLIDE # 16



* EXCEPT SODIUM, POTASSIUM AND IRON OXIDES WHICH ARE
PLOTTED AS PERCENTS



$$a = (X_{1,a}, X_{2,a}, X_{3,a})$$

$$b = (X_{1,b}, X_{2,b}, X_{3,b})$$

$$c = (X_{1,c}, X_{2,c}, X_{3,c})$$

$$d = (X_{1,d}, X_{2,d}, X_{3,d})$$

$$\Delta_{b,d}^2 = (X_{1,b} - X_{1,d})^2 + (X_{2,b} - X_{2,d})^2 + (X_{3,b} - X_{3,d})^2$$

From NUMERICAL TAXONOMY by Peter
H. A. Sneath and Robert R. Sokal.
W. H. Freeman and Company.
Copyright 1973.

SLIDE #17

Euclidean distance

$$\Delta_{AB} = [(X_A - X_B)^2 + (Y_A - Y_B)^2 + (Z_A - Z_B)^2]^{1/2}$$

Mean Euclidean distance in n dimensions

$$d_{AB} = (\Delta^2_{AB}/n)^{1/2} = \left(\frac{1}{n} \sum_1^n (X_{An} - X_{Bn})^2 \right)^{1/2}$$

City block distance

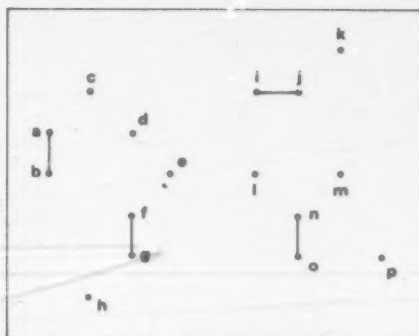
$$= |X_A - X_B| + |Y_A - Y_B| + |Z_A - Z_B|$$

Mean character difference in n dimensions

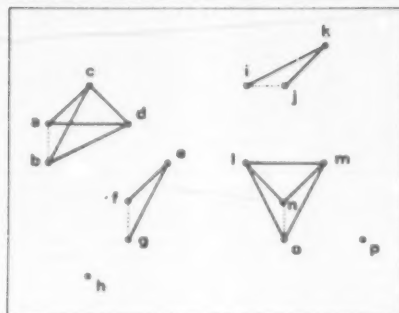
$$\text{M.C.D.} = \frac{1}{n} \sum_1^n |X_{An} - X_{Bn}|$$

SLIDE #18

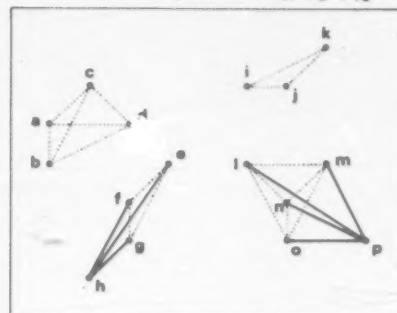
Step 1
Level of cohesion
(maximum link), $\Delta = 1$



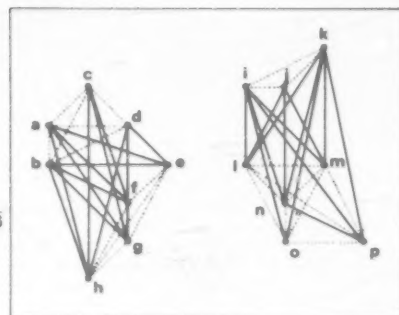
Step 2
Level of cohesion
(maximum link), $\Delta \leq \sqrt{5}$



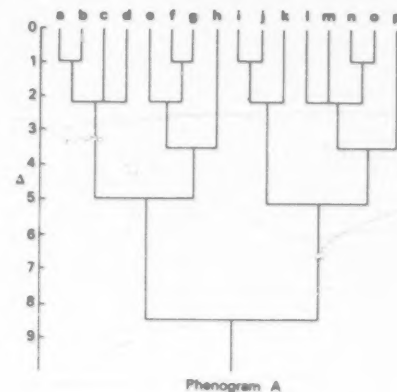
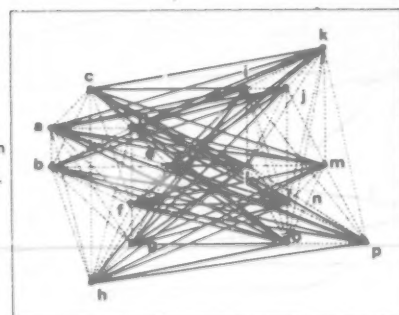
Step 3
Level of cohesion
(maximum link), $\Delta \leq \sqrt{13}$



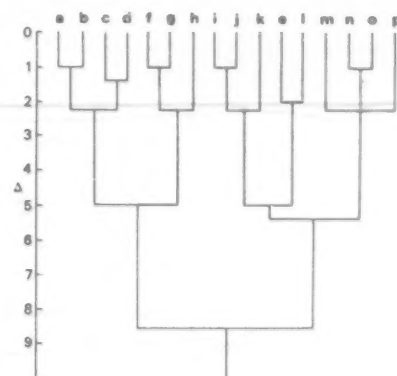
Step 4
Levels of cohesion
(maximum links)
Left cluster, $\Delta \leq 5$
Right cluster, $\Delta \leq \sqrt{26}$



Step 5
Level of cohesion
(maximum link),
 $\Delta \leq \sqrt{73}$



Phenogram A



Phenogram B

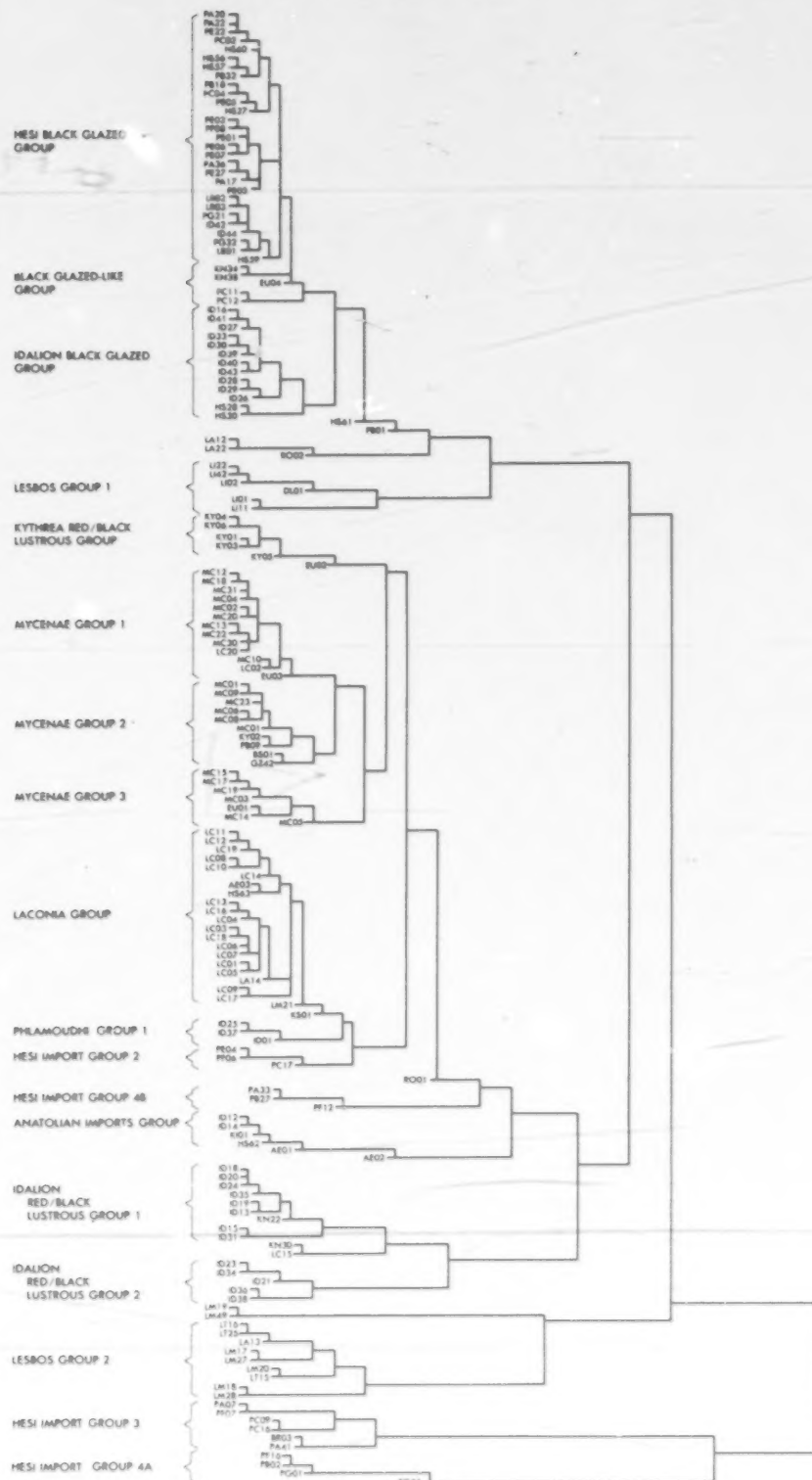
From NUMERICAL TAXONOMY by Peter
H. A. Sneath and Robert R. Sokal.
W. H. Freeman and Company.
Copyright 1973.

SLIDE #19

-525-

569

FIGURE 3. DENDROGRAM OF CLUSTERING
OF AEGEAN, GREEK, AND UNKNOWN SAMPLES.



SLIDE #20

-526-

570



SLIDE #21

571

572

-528-



SLIDE #22

573

574



SLIDE #23

APPLICATION OF NUCLEAR METHODS TO FOOD PRESERVATION AND AGRICULTURE

By
DR. EDWARD S. JOSEPHSON

Senior Lecturer
Department of Nutrition and Food Science
Massachusetts Institute of Technology
Room 56-109
Cambridge, Massachusetts 02139

APPLICATION OF NUCLEAR METHODS
TO FOOD PRESERVATION AND AGRICULTURE

I. Introduction

Food is a unique form of energy needed by humans. Whereas machines can use energy from a number of sources, humans can use energy only from material which we call foodstuffs, which are taken into the body by the mouth (or, in special cases, injected into the blood stream). The origin of food energy is the sun. This solar energy is stored in foods via photosynthesis, which converts carbon dioxide and water to glucose in the presence of chlorophyll in green plants. Healthy humans, through controlled biochemical reactions, are able to convert the energy stored in food to kinetic and thermal energy without elevation of body temperature more than a few degrees above 37°C.

In the broadest sense, therefore, the need to assure an ample food supply is one facet of the total energy problem confronting us.

II. National Policy

Historically, the United States has been the most fortunate nation in the world, endowed with a vigorous, healthy population with all the natural resources--the land, coal, oil, natural gas, minerals, and climate necessary to support the "good life". We have been endowed with a political system fostering an open society in which opportunities for each individual for life, liberty and pursuit of happiness are more favorable than almost anywhere else on earth. Two oceans have insulated

us from political turmoil and devastation from foreign wars. In this context, we did not, until now, feel the need to conserve, to recycle, to make do, to tighten our belts. Our government, which reflects the mood of the people, did not seriously discourage this nonconserving psychology. It is only just recently that the national energy policy has been changed by an announcement by the Energy Research and Development Administration "to raise the conservation of energy to a priority equal to that of building new energy sources."¹

Will those responsible for assuming an adequate amount of energy from food change our national policy and elevate conservation of food to a priority equal to that of increasing food production or finding new food sources?

III. The World Food Problem

Applying preservation technology to prevent food losses could be a major factor in helping solve the world food problem. If this technology were fully exploited, the quantity of food products today would be more than enough to feed the existing world population.²

Because of enormous spoilage losses in many developing countries, there is little incentive to raise livestock and poultry to help meet the daily animal protein needs of nonfarm populations. Fish protein, available from the sea, cannot reach inland areas for lack of efficient preservation methods. Thus, a large, protein-starved population is deprived of high-value protein. This serious deficiency in animal protein could at least be partially remedied by increasing the protein supplies by (a) increasing production, and (b) preserving what has been produced, in order to reduce the tremendous losses presently occurring

during handling, transport, and storage of these highly perishable commodities.

The following data exemplify annual spoilage losses:²

(a) Cereals and leguminous seeds in 9 Latin American Countries - 4.5 million tons (14 to 50% of the total produce of the countries concerned).

(b) Yams in West Africa - 1 million tons.

(c) Millet, sorghum, and kidney beans in Nigeria - 1.1 to 1.4 million tons.

(d) Potatoes and onions in India - 5 and 1.5 million tons, respectively (25% of the crop).

(e) Grain in India - 15% annually.

Other reports indicate:

(a) Food loss through spoilage after harvest is equivalent to 33 million tons of grain, or the production from 12 million acres of land.³

(b) The world food supply could be increased by 25 to 30% if postharvest losses could be avoided.⁴

These losses represent not only loss of product, but, just as importantly, losses in soil fertility, manual labor, and monetary expenditure. Agricultural production is achieved only at expense of vital energy reserves. In the United States of America, an average of 150 gallons of gasoline per person per year is required to grow and harvest food. The fertilizer industry consumes about 3% of the national gas supply.⁵ Thus, very real gains are possible through prevention of losses presently suffered during the storage of food.

Irradiation preservation could play an important role in preventing a large part of these food losses.

IV. Definitions of Terms Used in Radiation Preservation of Foods

Beta particle - A high-speed electron ejected from an atomic nucleus in certain types of radioactive disintegration. These electrons were described as beta particles before their identity as electrons had been established.

Curie - The unit of radioactivity. A curie was originally defined as the number of nuclear disintegrations occurring each second in 1 g of radium. It is now defined as that amount of radioactivity which involves the disintegration of 3.7×10^{10} atomic nuclei in 1 second.

Electron - A particle possessing a negative electric charge. It is an integral part of every neutral atom. It has a mass of 1/1840th of that of the hydrogen atom. Free electrons can be produced in various ways, collected into beams in a vacuum and accelerated in electrical machines to a high energy potential. Electrons and beta particles are identical in nature, the term beta particle being reserved to describe electrons originating from a disintegrating nucleus in radioactive decay.

Electron Volt (eV) - a unit of energy equivalent to the amount of energy gained by an electron when accelerated by a potential of one volt. One electron volt = 1.6×10^{-12} erg. Larger multiple units are used to describe the energy level of electrons and x-rays from electrical machine sources, or beta particles and gamma rays from radioactive sources, viz: 1 KeV = 1000; 1 MeV = 1 million eV.

Gamma Radiation - Electromagnetic radiation of a very short wavelength, produced by spontaneous disintegration of the atomic nucleus of

certain radioactive nuclides. Gamma rays are of the same nature as x-rays of short wavelengths.

Rad - The unit of energy absorbed from ionizing radiation by the matter through which the radiation passes. A radiation dose of 1 rad involves the liberation of 100 erg of energy into each gram of matter through which the radiation passes. Large multiple units are frequently used to express the radiation dose in food irradiation, viz: 1 Krad = 1000 rad; 1 Mrad = 1 million rad.

X-rays - Electromagnetic radiation of a wide variety of short wavelengths, usually produced by a machine in which a beam of fast electrons in a high vacuum bombards a metallic target. X-rays of short wavelengths are of the same nature as gamma rays except for their origin. X-rays are sometimes termed Roentgen rays.

Radappertization - Exposure to ionizing radiation of food in hermetically sealed packaging at doses necessary to kill all organisms of food spoilage or public health significance. Doses used are greater than 1 Mrad. Analogous to thermal sterilization (canning).

Radication - Exposure of food to ionizing radiation at doses necessary to kill all nonsporeforming pathogens. Doses used are generally below 1 Mrad. Analogous to pasteurization.

Radurization - Exposure of food to ionizing radiation to reduce populations of organisms in order to delay onset of spoilage. Doses used are generally below 1 Mrad. Analogous to pasteurization.

V. Contribution of Ionizing Radiation to Alleviate the World Food Problem

Ionizing radiation is highly versatile tool which can be used to alleviate the worldwide food shortage. Because there is only a slight

temperature rise in the foods exposed to ionizing radiation, these foods undergo changes in texture, flavor, odor, and color which are so minimal that on the plate of the consumer, they are almost indistinguishable from fresh food.⁶

Five distinct objectives can be achieved by irradiating foods:

(a) Total elimination of food spoilage and/or disease-causing bacteria, thus making prepackaged, enzyme-inactivated food stable for years without the need for refrigerated storage.

(b) Reduction of spoilage organisms sufficient to retard spoilage, thus extending refrigerated shelflife by weeks.

(c) Inactivation of all bacteria posing public health hazards, thus decreasing "food poisoning" potential of foods.

(d) Destruction of eggs and other life stages of insects infesting stored grains and fruits, thus preventing loss of these products during storage in insect-proof containers.

(e) Control of physiological processes to delay postharvest ripening in fruits, inhibiting sprouting in tubers (e.g., potatoes) and bulbs (e.g., onions), thus extending their storage life.

Ionizing radiation's unique capabilities for helping to alleviate the world food problem are apparent from the following:

(a) The radiation treatment can be deep and penetrating to achieve sterility or permit processing of food in large crates, or shallow and less penetrating to destroy spoilage organisms on the surface of food.

(b) There is great versatility in the sizes and shapes of the foods and food packages that can be preserved. The dimensions can range from large crates to sandwich-thin slices.

(c) Acceptance of irradiated foods by the consumer approaches that for analogous fresh foods.

(d) Nutritional quality of irradiated foods is as good as or better than that of food preserved by the older, well-established methods.

(e) Radiation processing of foods can reduce the dependence on chemical food additives currently needed for preservation or control of food-borne diseases. Continued use of some of these chemicals (fumigants for grain, biphenyl for inhibiting mold spoilage of oranges, nitrites for curing meats) is under review by health authorities because they may be dangerous to the health of the consumer.

(f) Irradiation is the only way to disinfest fruits (e.g., papayas) and grains of insects, to delay ripening of fruit (papayas, mangoes, tomatoes, bananas), and to inhibit sprouting of tubers (white potatoes) and bulbs (onions) without resorting to cooking, chemical additives, or other drastic measures.

(g) Ionizing radiation guarantees destruction of all food-borne disease-causing bacteria, molds, yeast, protozoa, and worms without resorting to drastic physical and chemical treatment.

(h) Use of ionizing radiation abates environmental pollution problems caused by alternate preservation methods which depend upon persistent chemicals.

The major drawback to the immediate use of ionizing radiation is the legal restriction in some countries where ionizing radiation is defined as a food additive (like chemicals) rather than as a physical method for food processing (like heat). This definition has slowed the process of obtaining approval from health authorities at national levels. Nevertheless, national health authorities in seventeen countries have already given limited or unlimited approvals for at least one of

twenty-five irradiation-processed foods (Table I).

VI. Sterile Male Technique to Control Populations
of Insects Destroying Food

The females of several species of adult insects destructive to food will mate only once. If the females mate with sterile males, they lay eggs which do not develop. This is a nonchemical method for reducing the population of these insects. Enormous numbers of male screwworm flies (Cochliomyia hominivorax) and Mediterranean fruit flies (Ceratitis capitata) reared in the laboratory and sterilized by exposure to ionizing radiation are released into the environment at the proper season. Since they far out number the fertile males present naturally, the chances are that the sterile males will mate with the females. The screwworm fly, a blue-green fly of the New World, breeds in the living tissue of mammals; it penetrates chiefly through open wounds. Its parasite larvae (screw-worm) cause serious injury or death to livestock. The sterile male technique to reduce or even eliminate losses in cattle has been successfully applied, first experimentally in Trinidad, and then on a large scale in the southeastern United States. The Mediterranean fruit fly is a black-and-white two-winged fly, found in most subtropical countries except those in North America. It attacks citrus and other fruits. The sterile male technique has been tested successfully in Capri and elsewhere.

VII. Mutations

A. Protein from edible plants is inferior to nutritional quality to protein from animal sources because plant proteins lack or have less of one or more amino acids essential for humans. Geneticists and plant

breeders have in recent years succeeded in developing or identifying mutations in corn, barley and sorghum which have significantly higher levels of lysine, one of the eight "essential" amino acids, as well as favorable alterations in levels of other amino acids, in their seed proteins. Additional research is needed to learn what further improvements in the nutritional quality of plant proteins can be achieved by inducing mutations through exposure to ionizing radiation.

B. Attempts are underway to produce radiation-induced mutants providing better crop yields and greater resistance to environmental extremes.

C. A radiation-induced mutant strain of Trichoderma (a mold) having four-fold the amount of cellulase than the parent strain has been obtained. This mutant is now being used as a source for cellulase to convert waste cellulosic materials to glucose on a semi-pilot-plant scale. The glucose syrup obtained can be used in production of non-photosynthetic single-cell protein. Alternatively, the glucose can be fermented to alcohol, a clean-burning fuel which could be used to stretch the gasoline supplies needed to run our engines and vehicles. It has been calculated that a 10% supplement to the world's food supply could be provided by a single-cell protein fermentor occupying an area equivalent to about 1.5 square kilometers of the earth's surface.⁷ At the same time, we would be helping to clean up the environment by using cellulosic waste.

VIII. Other Applications

Tracer techniques - Isotopically labelled tracers are widely used in basic and applied plant science to study processes of uptake, assimilation

lation, production, translocation, storage and excretion of various organic and inorganic compounds. The results of these studies can be applied to breeding hardier or nutritionally better plants through nondestructive in vitro tests. It should also be possible by using tracer techniques to study interactions of plants with microorganisms such as pathogens or nitrogen-fixing bacteria.⁸

Radiation treatment of sludge for fertilizer - A new research facility, located on Deer Island in Boston, Massachusetts harbor, to disinfect municipal sludge by using high energy electron treatment, was dedicated on May 19, 1976. This facility has a sludge treatment capacity of 100,000 gallons per day. The treated sludge, free of public health hazard, could be applied on land to promote plant growth and soil conditioning. This program is supported financially by the National Science Foundation/Research Applied to National Needs with the joint efforts of the Massachusetts Institute of Technology, the Metropolitan District Commission and the Water Resources Commission of the Commonwealth of Massachusetts, the University of New Hampshire, and the High Voltage Engineering Corporation.

GENERAL SURVEY OF IRRADIATED FOOD PRODUCTS CLEARED FOR HUMAN CONSUMPTION IN DIFFERENT COUNTRIES

(Grouped according to product)

September 1975

PRODUCT	COUNTRY	PURPOSE OF IRRADIATION	TYPE AND SOURCE OF RADIATION ⁶⁰ Co ¹³⁷ Cs electrons	DOSE (Krad)	DATE OF APPROVAL	
<u>Fruits & Vegetables</u>						
POTATOES	<u>USSR</u>	sprout inhibition	+	10	14 March	1958
		sprout inhibition		1 MeV max. 30	17 July	1973
	<u>Canada</u>	sprout inhibition	+	10 max.	9 November	1960
				15 max.	14 June	1963
	<u>USA (white potatoes)</u>	sprout inhibition	+	5 - 10	30 June	1964
			+	5 - 10	2 October	1964
			+	5 - 15	1 November	1965
	<u>Israel</u>	sprout inhibition	+	15 max.	5 July	1967
	<u>Japan</u>	sprout inhibition	+	15 max.	30 August	1972
	<u>WHO **)</u>	sprout inhibition	+	15 max.	12 April	1969
	<u>Spain</u>	sprout inhibition	+	5 - 15	4 November	1969
	<u>Hungary *)</u> ****)	sprout inhibition	+	10	23 December	1969
		sprout inhibition	+	15 max.	10 January	1972
	<u>Denmark</u> ****)	sprout inhibition	+	15 max.	5 March	1973
		sprout inhibition		10 MeV 15 max.	27 January	1970
	<u>Netherlands</u>	sprout inhibition	+	4 MeV 15 max.	23 March	1970

-541-

PRODUCT	COUNTRY	PURPOSE OF IRRADIATION	TYPE AND SOURCE OF RADIATION			DOSE (Krad)	DATE OF APPROVAL
			⁶⁰ Co	¹³⁷ Cs	electrons		
<u>Fruits & Vegetables</u> (cont'd)							
POTATOES (cont'd)	Bulgaria *)	sprout inhibition	+				1971
	*)	sprout inhibition	+			10	30 April 1972
	Uruguay *)	sprout inhibition	+				23 June 1970
	Philippines **)	sprout inhibition	+			15 max.	13 September 1972
	France **)	sprout inhibition	+			7,5 - 15	8 November 1972
	<u>Italy</u>	sprout inhibition	+	+		7,5 - 15	30 August 1973
	FRG *)	sprout inhibition	+			15 max.	26 September 1974
	<u>Canada</u>	sprout inhibition	+			15 max.	25 March 1965
	USSR *)	sprout inhibition	+			6	25 February 1967
	<u>USSR</u>	sprout inhibition	+			6	17 July 1973
ONIONS	<u>Israel</u>	sprout inhibition	+			10 max.	25 July 1968
	<u>Spain</u>	sprout inhibition	+			8 max.	1971
	Netherlands *)	sprout inhibition	+			15 max.	5 February 1971
	<u>Netherlands</u>	sprout inhibition	+			5 max.	9 June 1975
					4 MeV	15 max.	5 February 1971
	Bulgaria *)	sprout inhibition	+			10	30 April 1972
	Hungary ****)	sprout inhibition	+				5 March 1973
	****)	sprout inhibition	+			6	6 August 1975
	<u>Thailand</u>	sprout inhibition	+			10 max.	20 March 1973
	<u>Italy</u>	sprout inhibition	+	+		7,5 - 15	30 August 1973

PRODUCT	COUNTRY	PURPOSE OF IRRADIATION	TYPE AND SOURCE OF RADIATION		DOSE (Krad)	DATE OF APPROVAL	
			^{60}Co	^{137}Cs electrons			
GARLIC	Bulgaria *)	sprout inhibition	+		10	30 April	1972
	Italy	sprout inhibition	+	+	7,5 - 15	30 August	1973
DRIED FRUITS	USSR	insect disinfection	+		100	15 February	1966
FRESH FRUITS & VEGETABLES	Bulgaria *)	insect disinfection	+		100	30 April	1972
	USSR *)	radurization	+		200 - 400	11 July	1964
	Bulgaria *) (tomatoes, peaches, apricot, cherry, raspberry, grapes)	radurization	+		250	30 April	1972
MUSHROOMS	Netherlands	growth inhibition	+	4 MeV	250 max.	23 October	1969
ASPARAGUS	Netherlands *)	radurization	+		200 max.	7 May	1969
STRAWBERRIES	Netherlands *)	radurization	+	4 MeV	250 max.	" "	"
COCOABEANS	Netherlands *)	insect disinfection	+	4 MeV	70 max.	" "	"
SPICES & CONDIMENTS	Netherlands *)	radicidation	+	4 MeV	800 - 1000	13 September	1971
	Hungary *) (mixed spices: black pepper, cumin, paprika, dried garlic: for use in sausages)	radicidation, radappertization	+		500	2 April	1974
<u>Grain & Grain Products</u>							
GRAIN	USSR	insect disinfection	+		30		1959
	Bulgaria *)	insect disinfection	+		30	30 April	1972
WHEAT & WHEAT FLOUR (changed on 4 March 1966 from WHEAT PRODUCTS)	USA	insect disinfection	+		20 - 50	21 August	1963
				+	20 - 50	2 October	1964
				5 MeV	20 - 50	26 February	1966

PRODUCT	COUNTRY	PURPOSE OF IRRADIATION	TYPE AND SOURCE OF RADIATION			DOSE (Krad)	DATE OF APPROVAL	
			⁶⁰ Co	¹³⁷ Cs	electrons			
WHEAT, FLOUR, WHOLE WHEAT FLOUR	Canada	insect disinfection	+			75 max.	25 February	1969
WHEAT & GROUND WHEAT PRODUCTS	WHO **)	insect disinfection				75 max.	12 April	1969
<u>Meat & Fish</u>								
SEMI-PREPARED RAW BEEF, PORK & RABBIT PRODUCTS (in plastic bags)	USSR *)	radurization	+			600 - 800	11 July	1964
POULTRY, Eviscerated (in plastic bags)	USSR *)	radurization	+			600	4 July	1966
	Netherlands *)	radurization	+			300 max.	31 December	1971
	Canada ****)	radicidation (Salmonella)	+			700 max.	20 June	1973
CULINARY PREPARED MEAT PRODUCTS (FRIED MEAT, ENTRECOTE)(in plastic bags)	USSR *)	radurization	+			800	1 February	1967
SHRIMPS	Netherlands *)	radurization	+		4 MeV	50 - 100	13 November	1970
COD & HADDOCK FILLETS	Canada ****)	radurization	+			150 max.	2 October	1973
<u>Other Products</u>								
DRY FOOD CONCENTRATES (buckwheat mush, gruel, rice pudding)	USSR	insect disinfection	+			70	6 June	1966
	Bulgaria *)	insect disinfection	+			100	30 April	1972
ANY FOOD for consumption by patients who require a sterile diet as an essential factor in their treatment	UK	radappertization					1 December	1969

PRODUCT	COUNTRY	PURPOSE OF IRRADIATION	TYPE AND SOURCE OF RADIATION			DOSE (Krad)	DATE OF APPROVAL
			⁶⁰ Co	¹³⁷ Cs	electrons		
<u>Other Products (cont'd)</u>							
DEEP-FROZEN MEALS	Netherlands ***)	radappertization	+			2500 min.	27 November 1969
	FRC *) ***)	radappertization	+			2500 - 4500	24 March 1972
FRESH, TINNED & LIQUID FOODSTUFFS	Netherlands ***)	radappertization	+			2500 min.	8 March 1972

PREPARED BY: Dr. K. Vas
International Atomic
Energy Agency,
Vienna, Austria

*) experimental batches
**) temporary acceptance for 5 years
***) hospital patients
****) test marketing
underlined: unlimited clearance

R E F E R E N C E S

1. T. Ferrell and D. Johnston, in New York Times, Section 4, Page 7, Sunday, April 25, 1976.
2. Anon. "Aspects of the Introduction of Food Irradiation in Developing Countries", International Atomic Energy Agency, STI/PUB/362, Vienna, Austria, 1973.
3. J. R. Hickman, "Food Irradiation: Problems and Promises", Bulletin 16(5), 30-34 (1974), International Atomic Energy Agency, Vienna, Austria.
4. H. R. Goresline, "The Potentials of Ionizing Radiation for Food Preservation", Food Irradiation Information, No. 2, 20-34 (1973). Published by the International Project in the Field of Food Irradiation, Karlsruhe, Federal Republic of Germany.
5. Anon. Editorial, "Energy for Agriculture", Agriculture Research 22, No. 2, 2 (1973).
6. E. S. Josephson, A. Brynjolfsson, and E. Wierbicki, "The Use of Ionizing Radiation for Preservation of Food and Feed Products" in Radiation Research, Biomedical, Chemical and Physical Perspectives, (O. F. Nygaard, H. I. Adler & W. K. Sinclair, eds), pp. 96-117. Academic Press, New York, 1975.
7. N. S. Scrimshaw, D. I. C. Wang and M. Milner, "Protein Resources and Technology: Status and Research Needs. Summary and Research Recommendations", NSF RA-T-75-037, December 1975. Superintendent of Documents, Government Printing Office, Washington, D.C. Stock Number 038-000-00251-1.
8. A. Micki, "In Tracer Techniques for Plant Breeding", International Atomic Energy Agency, STI/PUB/419, Vienna, Austria, 1975.

NUCLEAR METHODS IN CRIMINOLOGY

**By
DR. GEORGE NELSON**

**College of Engineering (Nuclear)
The University of Arizona
Tucson, Arizona 85721**

NUCLEAR METHODS IN CRIMINOLOGY

Modern crime labs make use of a large number of scientific techniques which were unknown a generation ago. Some make use of modern nuclear technology. All of these techniques serve one of the following purposes:

1. To determine whether a crime has been committed. For example, to analyze for poisons.
2. To provide leads in the investigation of a crime to identify possible suspects. For example, to identify the kind of automobile involved in a hit-and-run, where the only evidence is glass or paint.
3. To provide information which can be used as admissible evidence in a court case.

Nuclear techniques are one among many different types of chemical, physical, and visual methods. Most chemical techniques can be used to determine what chemical compounds are present. The nuclear techniques tell only whether certain elements are present in a sample and how much is present.

The nuclear techniques involve either:

1. Activation of the nucleus of atoms by neutron absorption. The radiation which is given off at the time of neutron absorption, or a short time later, is characteristic of the element. Thus, for example, one can determine whether arsenic is present in a sample and how much is present. This is called neutron activation analysis.
2. Activation of the electrons surrounding atoms by bombarding them with an x-ray beam. The electron rearrangements are accompanied by low energy x-rays whose energy can be measured and which are characteristic of the elements present. This is called x-ray spectroscopy.

Each of these two nuclear techniques has its advantages and disadvantages. One disadvantage of neutron activation analysis is that many elements are not activated (do not become radioactive) when they absorb a neutron. A disadvantage of x-ray analysis is that the characteristic x-rays are emitted from the sample only during the time the activating x-ray beam is on. Also, since the characteristic x-rays have low energy, some of them will be absorbed in the sample. This makes it difficult or impossible to get good quantitative data from analysis of thick or nonhomogeneous samples.

The advantages of both techniques are that they are sensitive to very small concentrations of many elements--to the billionth of a gram in many cases--and they are also usually non-destructive. This is important, since it is valuable to be able to submit the original samples as evidence in court after tests have been performed. In most chemical analyses, the sample is consumed by the analysis and thus, is not available for submission as evidence.

The kinds of cases where nuclear techniques are valuable include:

1. Determining whether poisonous elements are present in samples from autopsies or in food or utensils.
2. Identifying the presence of unlawful amounts of certain elements in food or drugs (for example, mercury in canned tuna fish).
3. Identifying gunshot residues on hands, clothing, or other surfaces.
4. Identifying, by means of trace element content, the place of origin of drugs, soil, or bullet fragments.
5. Matching samples collected at the scene of a crime with other samples collected from suspects. These may include hair, fingernail fragments, blood, paint, glass or drugs.

Any techniques used in criminal cases require a lot of time, and must be done with the utmost of care. Any situation which could compromise the security of a sample or the accuracy of its analysis, could totally negate its value in court. For example, evidence could be disqualified because of a possibility that a sample was mislabeled, or if it was momentarily out of the hands of its custodian, or if it was handled improperly. The samples are often small with no opportunity for duplicate analyses.

In order to prove the common origin of hair, glass, paint, etc., a very large amount of data must previously be collected on the range of distribution of the elements measured in the general population. This data is used to calculate a probability of two samples having common origin--such as being able to state that only one person in 100,000 will have the concentration of the measured elements in his hair agreeing to the degree observed. To be able to make this statement, thousands of hair samples must be analyzed previous to the time the evidence is analyzed.

Perhaps the biggest disadvantage of the nuclear techniques in criminology is the fact that few laboratories are available where the analysis can be performed. Most samples are sent to the FBI for analysis at the National Bureau of Standards Reactor. The person who performed the analysis will have to be present to present the results in person and explain the techniques used, before it is admitted as evidence. This means the costs are very high to use this technique in routine cases.

Nuclear techniques in criminology are valuable because they sometimes provide unmistakable evidence which no other existing technique

can do. This is because of the extreme sensitivity and low levels of detection. Still, these techniques form only a small part of the arsenal of present-day forensic science.

HEALTH EFFECTS OF ENERGY PRODUCTION AND CONVERSION

By
DR. CYRIL L. COMAR

Director
Department of Environmental Assessment
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

HEALTH EFFECTS OF ENERGY PRODUCTION AND CONVERSION

INTRODUCTION

Historically, the development of technology has not been guided by particular concern for associated health effects. It is now becoming clear that future technological assessment will almost certainly require some prior attention to health impacts. This reflects the preception that the health effects of technology have not been internalized, i.e. they are either inadequately compensated for in the working population or are borne by segments of society not directly benefiting from the responsible industry. Black lung disease of coal miners is an example of the former; disease produced or aggravated by industrial smogs is an example of the latter.

There are a number of compelling reasons for attempting some assessment of health effects related to energy even though such estimates may, because of inadequate data, lack precision. The development of national energy policies and strategies, including difficult choices among fuel systems, must be guided not only by market economics but by careful consideration of health and environmental effects not necessarily reflected in pricing. Another reason for health-effects assessment is to permit rational and cost-effective safety and control procedures. Miscalculation of the risks involved can create severe dislocations, diseconomies, or hazards: for example, excessive expenditures on construction or equipment out of proportion to risk, or in the other extreme, inadequate expen-

ditures to protect life and health. Finally, the attempted assessment of health effects can provide guidance as to research needs and priorities.

It is important that the scientific community not only provide data and interpretations for policymaking bodies but also assure that the broad implications are understandable by the general public. There have been major shortcomings in the general understanding of the impacts of health effects. One of these has been the emphasis on individual energy systems treated in isolation rather than comparisons of the various systems available, each of which has its own attendant risks. Knowledge of the health effects associated with a given type of power plant is by itself of little value. For example, if a given nuclear plant is not built, then for the near and midterm future a coal plant must be built in its place or no plant at all. (It is assumed that oil and natural gas will be in short supply and that other possibilities such as geothermal, fusion, solar, wind, tide, etc. either have such limited application or are so uncertain that it would be highly imprudent to rely on them for the needs of the next 10-30 years. Each of these potential sources should, however, be researched as intensively as feasible and brought into commercial production whenever possible.) It is beyond the scope of this paper to consider the biological risks associated with inadequate supplies of electricity, but it is by no means certain that a coal plant or no plant at all would have less health impact than would a nuclear plant.

A second shortcoming is that health effects have usually been expressed in absolute terms as numbers of either premature deaths or serious disabilities. Assessments presented in this way are most difficult to relate to the real significance that they have for individuals.

We propose that it would be much more helpful to convert this measure to the degree of enhanced risk to which individuals and the population are exposed. Still another technique for presentation of these risks is through conversion to a dollar cost. This concept, although particularly useful in evaluating safety expenditures, is beyond our scope and is not developed further here. Nor is there consideration of abatement and control procedures or their cost-effectiveness.

The data are limited primarily to the production of electricity because of the increasing importance of this energy form in our society and because various fuel options are available. Following discussions of some basic principles in consideration of health effects, the available health-effects data are presented for fuel extraction, transport, processing, and electricity generation from the major fuel systems with emphasis on the major uncertainties and controversies.

HEALTH EFFECTS: THEIR NATURE AND MEASUREMENT

General

The National Academy of Sciences has recently published a report (1) that contains numerous references to support the general statements of this section and is a perceptive treatment of what man needs to know to deal effectively with chemicals in the environment. References 2-6 are comprehensive reports that cover health effects of air pollution with emphasis on the role of fossil fuel combustion products. References 7-11 provide the basic documentation on the biological effects of radiation, and references 12 and 13 deal with concepts of benefit and risk.

Health consequences of technology cover a wide spectrum ranging from mere nuisance to violent death. They may be transient or permanent. They

may be localized or may affect worldwide populations, as from nuclear fallout. The noxious agents may be chemical, physical, or biological; they may be synthetic, and therefore their presence identified easily, or they may be naturally occurring and appear only as an increased concentration of a natural element, e.g. mercury, lead, arsenic. The pollutant source may be obvious, as in the case of a noisy airport, or it may be obscure, as in the case of commingled combustion products in city air. The resultant health effects may be obviously and immediately related to the cause, as with asbestos-induced lung cancer; or the relationship may be obscure, as with the London smog of 1952, which was unrecognized until identified retrospectively by careful epidemiologic analysis of mortality statistics. Acute effects (those following soon after relatively large exposure) are generally more easily related to their causative factors than are chronic effects. Chronic exposures to routine releases of pollutants generally cause effects that are far more difficult to recognize; they often result in an increased frequency of a disease that occurs "naturally" in the exposed population.

There can be considerable individual variation in response to pollutants. For example, groups that appear to be more sensitive to air pollution include young children, possibly because of higher inspiratory rates, more mouth breathing, and frequent respiratory tract infection; aged persons, possibly because of decreased cardiopulmonary adaptive capacity; asthmatics; persons with preexisting chronic bronchitis and emphysems; certain occupational workers; and smokers. Generally, the fetus and the infant are more susceptible to toxic exposures than are adults. Effects from fetal exposure may also appear as congenital malformations, as from the use of thalidomide or from maternal rubella;

these agents are known as teratogens.

Probably no health effect of pollutant exposure is of greater public concern than cancer. That cancer can follow environmental exposure to chemical carcinogens has been known with some certainty ever since the eighteenth century when Sir Percival Potts recognized scrotal cancer in the chimney sweeps of London, undoubtedly induced by the hydrocarbons of soot. Although it is not known to what extent cancers of all organ systems are the result of exposure to chemical carcinogens, experts ascribe the majority to this source. Probably the best recognized relationship observed on a large scale in the general public is between lung cancer and cigarette smoking, but a number of other agents are known or suspected as carcinogens. One of the difficulties hindering investigators is the long latent period between exposure and development of the cancer, which may appear decades later when occupation or exposure may have changed. Furthermore, better understanding is complicated by the possibility of synergistic or additive effects among various agents that individually may be weak carcinogens, difficult to identify. Although cancer is generally a "somatic" effect, i.e. occurring in the person exposed, it may be mediated by a genetic mechanism operating on the informational macromolecules at the cellular level. The implications, which are discussed later, are that since only one or a few target molecules may need to be modified to produce cancer there is some chance of harm at any exposure level above zero, although repair mechanisms may operate at low dose rates.

The classes of carcinogenic agents identified as present in products of fossil fuel combustion and nuclear effluents are: (a) polycyclic and other aromatic hydrocarbons, (b) trace metals, and (c) radionuclides.

They are often found associated with particulate matter. It must be noted that all of these agents are present in routine effluents in amounts that are too small to produce detectable effects, so that there is considerable uncertainty as to their actual impact on man. Lung cancer has been more studied by epidemiologists than any other cancers that might be associated with air pollution. The evidence presently available does not support--nor does it deny--the conclusion that air pollution per se is a causative factor (6).

Genetic effects, i.e. those occurring in the progeny of the exposed persons, are caused by a class of agents called mutagens. Although mutations confer on species the ability to evolve and react to new environmental conditions, most often such new characteristics are detrimental to the individual. Mutational changes may vary in severity from lethal effects to subtle effects that are not associated with mortality. Uncertainty as to how genetic effects of environmental agents will express themselves makes their recognition and quantification difficult if not impossible. In fact, no genetic effects from any agent have yet been found in human populations that can be traced with any certainty to parental exposures. Because of the great amount of research done on the genetic effects of ionizing radiation it is possible to predict the types and numbers of effects that would be produced in human populations from low levels (about natural background) even though none have been detected.

Exposure-Response Relationships

Attention is directed towards a dilemma that arises from dissemination of pollutants where there are large populations exposed to detectable

levels of a contaminant known to be harmful at some high level. The outstanding example is ionizing radiation produced from nuclear weapons testing. As a result of weapons testing, it has been demonstrated that practically every living organism on the earth contains detectable amounts of man-produced radioactivity, which is known definitely to be harmful at high levels. The potential for harm has caused great amounts of money and manpower to be spent for research since the middle 1940s, and it is fair to say that we know much more about ionizing radiation and its effects than about any other agent, chemical, or drug to which man exposes himself. The problem became visible because of the extremely sensitive means of detection. Since that time, there have been developed sensitive measures for various chemical pollutants in the biosphere that could be potentially harmful, so that we are faced with concerns and public reaction to such contaminants as mercury in fish, vinyl chloride from plastics, asbestos fibers, chlorinated hydrocarbons in purified water, pesticides, and sulfur compounds, nitrogen oxides, polycyclic organic materials, and trace elements from fossil fuel combustion. This public sensitivity understandably brings about great pressure to reduce the possible harm to zero or near-zero. To present the problem of both protecting the public welfare and persuading the public to realize that it must accept certain risks, we give a gross classification of the relationships between the level of a harmful agent and its effects. The solid lines represent levels of exposure ranging from high to zero; on the right are described effects caused by the corresponding level.

<u>Level of Exposure</u>	<u>Effect</u>
High -----	Death
Range A -----	Clinical symptoms
Range B -----	Undetectable effects at high probability
Range C -----	Undetectable effects at low probability
Zero -----	No effects

For any pollutant, there will be some high level that will cause lethal effects and a large proportion of deaths in the population exposed. Below that will be a range of levels (Range A) in which only clinical signs in the population are observed and the proportion of deaths, if any, is much lower. These clinical symptoms, as in the case of radiation effects or a pollutant-produced persistent cough, may not themselves be long-term contributors to ill health, but may denote an associated high probability of serious late effects. At still lower levels (Range B) the effects may be undetectable either directly or statistically, but yet they occur at high enough probabilities that society usually decides not to tolerate them. These can be effects that are undetectable at high or low frequency because they are minor in character, or they can be serious health effects that are undetectable because they are of low frequency and occur either immediately or (with radiation, for example) at some later time or in a later generation; in this paper we deal with the latter. Ionizing radiation is an agent about which enough is known so that levels in this range can be specified. At the present guidelines for radiation protection, no effects can be clinically or epidemiologically observed in exposed populations, although on the basis of radiobiological theory it

is postulated that effects do or could occur. Referring again to any pollutant, at even lower levels (Range C) the probabilities of effects may be so low that society is justified in accepting them if they are more than compensated by the associated benefits of the process that produces the harmful agent.

To further understand the need for risk acceptance, we must distinguish within Range C between two types of agents: the "threshold" and the "nonthreshold." For so-called threshold agents there is some level of pollutant below which no effects occur. For nonthreshold agents there are effects at any level of pollutant above zero. In terms of regulatory procedures, standards can be set for threshold agents that guarantee absolute safety. However, for nonthreshold agents there must be acceptance of some level of risk unless the agent can be completely eliminated. To protect the public and at the same time to provide the benefit of the process that produces this agent, it is desirable to establish regulations so that the population exposure falls somewhere within Range C. To do this it is usually necessary to ascertain the slope and nature of the exposure/effects relationship in the regions of interest so that there can be recommended public acceptance of certain levels of risk commensurate with associated benefits.

Risks of Death

As already mentioned, health effects range from the trivial to those causing severe disability and premature death. Attention in this paper is focused on the latter, mainly because they are the most important and we have no meaningful way of evaluating many of the less serious effects. It should also be noted that even premature deaths are not equivalent in

their impact on individuals and society. The ethical ideal that every being has a right to be born without man-induced effects and to die from old age (the natural wearing out of the body) is fully recognized. However, it is obvious that all early deaths do not have the same societal and personal impact. For example, the death of an early embryo before anyone even knows about it or the death of an elderly person a few months before he or she would otherwise die of old age would penalize neither the individual, the persons left behind, nor society, as would the death of a young adult, with family responsibilities, on the brink of a productive career. In addition, genetic effects can produce over a lifetime a variety of suffering and health effects, which, while they do not necessarily cause premature deaths, do constitute a social cost. At present it is not possible in the formulation of risk value to estimate the number of person-years lost because of exposure to the agent and to weigh them so that societal and personal impacts are taken into account. In this discussion the numbers are rounded and concepts are

Table 1. Normal risk of death per year in the United States as related to age (1969 data) and comparison of high and low additional risks.

Age	Normal Risk of Death per Year (14)
5	1 in 1587
10	1 in 3846
25	1 in 690
35	1 in 465
45	1 in 205
55	1 in 88
65	1 in 39
All ages	1 in 100
Added risk of death per year	
High risk	1 in 100 or less to 1 in 10,000
Low risk	1 in 10,000 to 1 in 1,000,000 or more

presented in a simple form that hopefully will lead to correct interpretation as well as facilitate understanding. The attempt is primarily to assess the health consequences associated with energy in terms of effects on individuals in the general population.

Table 2. Effects of accepting additional risks

	10-Year-Old	50-Year-Old
Risk of death/year	1 in 3800	1 in 100*
Normal risk/year plus additional risk/year of 1 in 10,000	1.38 in 3800	1.01 in 100
Normal risk/year plus additional risk/year of 1 in 1,000,000	1.0038 in 3800	1.0001 in 100

*This corresponds to the risk faced by the US population at large: 2×10^6 deaths per year/ 200×10^6 persons.

In the United States, with a population of about 200 million, about 2 million people die each year from all causes, such as old age, sickness, accidents, homicide, and suicide. This means that for the population at large in the United States there is a probability of dying in a given year of $0.01 \left[= (2 \times 10^6) / (200 \times 10^6) \right]$, or expressed another way, a risk of death in any year of 1 in 100. This risk is age-dependent, as can be seen in Table 1. It is usually considered that an additional man-produced risk of death per year, consciously accepted, is high if it falls in the range of 1 in 100 or less to 1 in 10,000 and low if it falls in the range of 1 in 10,000 to 1 in 1,000,000 or more.

To convey more easily the implications of accepting additional risks, we propose that data be calculated in terms of what the enhanced risk per year from a given activity will be. This is illustrated in Table 2. The 10-year-old who accepts an additional risk of 1 in 10,000 will change his overall risk from 1 in 3800 to 1.38 in 3800, a considerable proportional

Table 3 Premature deaths per year associated with operation of a 1000-MWe power plant (values are lowest and highest estimates from cited references)^a

	Coal	Oil	Natural Gas	Nuclear
Occupational				
Extraction				
Accident	0.45-0.99 (15, 17, 18, 21, 22)	0.06-0.21 (15-18, 22)	0.021-0.21 (15-18, 22)	0.05-0.2 (15, 17, 18, 20, 22)
Disease	0-3.5 (17)	—	—	0.002-0.1 (17, 19, 20, 22)
Transport				
Accident	0.055-0.4 (15, 17, 18, 22)	0.03-0.1 (15-17, 22)	0.02-0.024 (15, 17, 18, 22)	0.002 (15, 18, 22)
Processing				
Accident	0.02-0.04 (17, 18)	0.04-1 (15-18, 22)	0.006-0.01 (15, 17, 18, 22)	0.003-0.2 (15, 17, 18, 20, 22)
Disease	—	—	—	0.013-0.33 (17, 19, 20, 22)
Conversion				
Accident	0.01-0.03 (15-18, 22)	0.01-0.037 (15-18, 22)	0.01-0.037 (15-18, 22)	0.01 (15, 17, 18, 22)
Disease	—	—	—	0.024 (20)
Subtotals				
Accident	0.54-1.5	0.14-1.3	0.057-0.28	0.065-0.41
Disease	0-3.5	—	—	0.039-0.45
Total	0.54-5.0	0.14-1.3	0.057-0.28	0.10-0.86
General Public				
Transport	0.55-1.3 (15, 17, 21, 22)	—	—	—
Processing	1-10 (17)	—	—	—
Conversion	0.067-100 (17, 21)	1-100 (17)	—	0.01-0.16 ^b (15, 17, 19, 20, 22)
Total	1.6-111	1-100	—	0.01-0.16
Total Occupational and Public	2-116	1.1-101	0.057-0.28	0.11-1.0

^a Note: Dashes indicate no data found; effects, if any, are presumably too low to be observed; and no theoretical basis for prediction.

^b For processing and conversion.

Table 4 Occupational injuries per year associated with operation of 1000-MWe power plant (values are lowest and highest estimates from cited references)

Occupational Injuries	Coal	Oil	Natural Gas	Nuclear
Extraction				
Accident	22-49 (15, 17, 18, 22)	7.5-21 (15-18, 22)	2.5-21 (15-18, 22)	1.8-10.0 (15, 17, 18, 22)
Disease	0.6-48 (17, 21)	—	—	—
Transport				
Accident	0.33-23 (15, 17, 18, 22)	1.1-9 (15-17, 22)	1.2-1.3 (15-17, 22)	0.045-0.14 (15, 18, 22)
Processing				
Accident	2.6-3 (17, 18)	3-62 (15-18, 22)	0.05-0.56 (15-17, 22)	0.6-1.5 (15, 17, 18, 22)
Conversion				
Accident	0.9-1.5 (15-18, 22)	0.6-1.5 (15-18, 22)	0.6-1.5 (15-18, 22)	1.3 (15, 17, 18, 22)
Totals				
Accident	26-77	12-94	4-24	4-13
Disease	0.6-48	—	—	—

increase (38%). An older person (about 50 years of age) who accepts the same additional risk will change his overall risk, for example, from 1 in 100 to 1.01 in 100, a change of much less significance (1%). As indicated in Table 2, the acceptance of an additional risk of 1 in 1,000,000 produces changes of little significance regardless of age. These additional risk values can also be used to estimate the total number of individuals in an exposed population who may be affected. For example, an industrial process that imposes an additional risk per year of 1 in 10,000 on the population of the United States could cause 20,000 casualties per year $\sqrt{(200 \times 10^6)/10,000}$.

The following comparisons may be cited not to justify any additional risks, but to relate these probabilities to everyday risks. A person while riding in a car in the United States has an additional probability of death per year of about 1 in 100^1 ; this is a risk we accept, but for the 10-year-old, as an example, this represents about a fortyfold increase of normal risk. The risk of death from being struck by lightning or from a snakebite is about 1 in 1,000,000 per year.

HEALTH EFFECTS FROM ELECTRICITY GENERATION

Quantitative Data

Several reports have been published that contain estimates of the health effects associated with electricity production (15-22). We have constructed Tables 3 and 4 to summarize the available estimates for each phase of the fuel cycle for each of the four fuels: coal, oil, natural

¹The physical meaning of this risk estimate is confusing because of the time units; the absolute risk would be 1 in 100 if a person spent full time during the year riding in a car. The risk of death per hour while riding is 1 in 876,000, which is the same as the normal risk of death per hour of the 50-year-old person. Essentially, this means that while riding in a car, the risk of death of this person is about double.

gas, and nuclear. By and large, the estimates relate to contemporary technology and existing circumstances. In each case the data have been adjusted to represent the number of premature deaths or occupational impairments produced per year by processes associated with a 1000-MWe power plant, which is roughly that required for a population of 1,000,000 people. The values given represent the lowest and highest from the cited references. The references should be consulted for an understanding of the methodology and detailed assumptions; limitations are discussed in later sections.

Consider first from Table 3 the effects on workers. For coal-fired plants the values range from 0.5 to 5 premature deaths per year and for the other fuel sources they range somewhat lower, from 0.06 to 1.3. Most of these effects are due to accidents in coal mines, to conditions that cause black lung disease, or to activities in oil refineries, uranium mining, and nuclear fuel reprocessing.

Consider now from Table 3 the effects on the general population. It has been estimated that the transport of coal required for a year's operation of a 1000-MWe plant is responsible for 0.6 to 1.3 premature deaths by accidents at railroad crossings; no estimates are available for truck or barge transport. The comparative values for the other fuel systems are insignificant.

The data so far discussed have a reasonable statistical base of past operation and are to that extent reliable. The number of premature deaths among the public from power plant operation (conversion or generation of electricity) results primarily from dissemination of air pollutants and, as discussed later, these effects are a matter of great uncertainty. The upper-limit estimates for coal and oil are about 100

premature deaths per year compared with 1 or less for natural gas and nuclear.

Table 4 presents data on the number of nonfatal occupational injuries per year associated with the operation of a 1000-MWe power plant. These have been defined as injuries serious enough to cause loss of working time for several days or more. These effects are roughly the same for coal and oil, ranging from about 12 to 100 cases per year, and somewhat lower for natural gas and nuclear. Most of these effects are associated with mining, well digging, coal transport, oil refining, and nuclear reprocessing.

Fossil Fuels

The data presented on the health effects associated with fossil fuels suffer from certain limitations and uncertainties. First, genetic effects are not included because our present state of knowledge does not allow even an approximate estimate for such effects. Second, the data do not adequately discriminate between premature deaths that may occur early in life, such as from accidents, and those that may shorten life only slightly, as seen, for example, in increased mortality among persons hospitalized for chronic disease, who already have high mortality rates. Perhaps of greatest importance is the uncertainty about the validity of the upper estimates for the effects on the general public from burning coal and oil. Not only is there the problem of the magnitude of the effect, but lack of knowledge about the causative agents makes it difficult to institute effective control procedures.

The primary data come from epidemiological studies. Major episodes (Meuse, Donora, London, New York City, etc) clearly showed that air pol-

lution, sufficiently severe, could cause illness and premature death. During the 1950s and 1960s the major issue was whether air pollution in concentrations usually existing over industrial cities would cause adverse health effects. The emphasis shifted next to quantifying pollution relative to effects produced and more recently to the effects of low levels of pollution and the effects of interactions.

From a methodological standpoint epidemiological, animal, and experimental human studies are needed. Epidemiological studies are important to uncovering possible associations that can then be tested under controlled conditions; they are also needed for evaluation of human risks suggested by laboratory experiments. Animal studies are used to determine efficiently the sites of effects, mechanisms, and dose-response relationships, and they are more easily adapted for chronic studies than are human investigations. Because of species differences, controlled studies on humans are needed to establish specific responses and to determine the influence of disease or of various physiological states on the effects of pollution.

In this review, it is not possible to do more than present some general conclusions. Attention is called to a recent and comprehensive document (3, Chaps. 1-4) that references about 380 articles in this subject area.

In 1970, air quality standards for selected pollutants were mandated by the United States Clean Air Amendments. Emphasis was placed on sulfur dioxide because of the evidence that ambient levels were associated with health effects of air pollution disasters. Subsequent studies indicated that sulfur dioxide by itself could not be the primary causative agent and it was postulated that a combination of sulfur dioxide and particulates was responsible (23-25). More recent evidence suggests that oxidation

products of sulfur dioxide (i.e. sulfuric acid and particulate sulfates) --possibly acting synergistically with sulfur dioxide and other pollutants such as nitrates, particles, and ozone--are primarily the causative agents (26-28). It must be emphasized that although suspended sulfates are now being used as an indicator of health effects and there appear to be correlations between them and such effects, there is no firm evidence as to which substance or substances in polluted air are the causative agents. Without such knowledge, air pollution control strategy based on reduction of sulfur alone does not have a valid scientific basis.

The major categories of health effects associated with air pollution are (a) chronic respiratory disease; (b) symptoms of aggravated heart-lung disease; (c) asthma attacks; (d) children's respiratory disease; and (e) premature death. It would be most useful to understand the quantitative relationships between exposures to specific agents and these health effects in order to know how much investment is justified for control measures, to know which chemical effluents to control, and to make comparisons with biological costs of nuclear power.

In a recent report of the National Academy of Sciences-National Academy of Engineering-National Research Council (3, Chap. 13), illustrative calculations were made of the health effects associated with sulfur oxide emissions for representative power plants in the Northeast. The results are presented in Table 5. They were derived from models that related ambient levels to emissions including factors for conversion of SO_2 to sulfates; health effects from ambient levels were calculated by using dose-response curves from epidemiological data from studies of the Environmental Protection Agency (EPA). It must be emphasized that the numerical estimates of Table 5 are controversial, relying on limited

information and numerous arbitrary assumptions, and cannot be regarded as proven results. A critique in the same document from which Table 5 was derived (3, Chap. 4) suggests that the estimates could be low by a factor of two or high by a factor of ten. What can be concluded from Table 5 with reasonable assurance is that the effects listed are produced at detectable levels by factors associated with air pollution, with power plants most likely making a significant contribution. It should also be noted that a cost-benefit assessment of the data in Table 5 indicates that the economic impact of the nonlethal effects is much greater than that of the premature deaths.

Nuclear Power

Health risks to both the general public and occupational personnel from the nuclear fuel cycle are considerably better estimated than those from fossil fuel combustion. This is because (a) there is a single causative agent released from the nuclear plant--ionizing radiation--whereas there are literally hundreds of individual species released from fossil fuel combustion; (b) since the first nuclear weapons tests in the 1940s, about a billion dollars have been spent on research on the effects of ionizing radiation; (c) radiation exposures are easily and precisely measured; and (d) there is a great body of knowledge from natural background exposure and from accidental, industrial, and military exposures of populations.

The uncertainties and limitations in regard to nuclear fuel are somewhat different from those for fossil fuel combustion. The primary concerns cannot be completely answered by scientific evidence or technical solutions. They include such factors as (a) validity of predictions of

Table 5. Health effects associated with sulfur oxide emissions*

	Remote Location	Urban Location
Cases of chronic respiratory disease	25,600	75,000
Person-days of aggravated heart-lung disease symptoms	265,000	775,000
Asthma attacks	53,000	156,000
Cases of children's respiratory disease	6,200	18,400
Premature deaths	14	42

*Source: (3, Chap. 13). Illustrative calculations based on distributive models, postulated conversions of SO₂ to SO₄ and EPA epidemiological data for representative power plants in the Northeast emitting 96.5×10^6 pounds of sulfur per year--equivalent to a 620-MWe plant.

effects and frequency of catastrophic accidents; (b) the need for long-term and adequate management of radioactive wastes; and (c) problems of malevolence. The upper-limit values quoted in Table 3 are most likely overestimates for reasons discussed later in connection with the report by the Advisory Committee on the Biological Effects of Ionizing Radiation (BBIR) (7); although genetic effects are not included, there are enough data to indicate that the values given for nonaccidental premature deaths would not be increased by more than about 50% in the first generation or by more than severalfold after hundreds of years if genetic effects had been taken into account.

Generally speaking, the biological effects of ionizing radiation can be correlated with the dosage received. The effects on human individuals and populations can be considered most meaningfully in terms of two levels of exposure:

High-Level: Acute, whole-body exposure greater than tens of rems,² which could result from nuclear warfare or from catastrophic nuclear or other radiation accidents.

Low-Level: Partial or whole-body exposure, usually chronic and of the order of natural background (1 rem/year) or less, which could result from normal occupational exposure, fallout to date, a normally operating nuclear power industry, and miscellaneous sources such as television, jet travel, and luminous watch dials.

High-level exposures can and have produced directly observable manifestations. Acute exposures of about 1 rem can be harmful to the fetus. Low-level exposures, as defined above, have not produced detectable deleterious effects in human individuals or populations or in other living organisms. This does not mean that such effects do not occur; it means that if they do occur, they do so at such low frequencies as to be undetectable.

HIGH-LEVEL EFFECTS High-level doses of ionizing radiation may produce both acute and delayed effects in humans or other organisms. The gross, acute effects of whole-body exposure to high-level doses are summarized in Table 6. Delayed effects may be noted after partial-body exposure to high-level doses; usually they are a result of hundreds to thousands of rems administered therapeutically to localized areas of the body. Such delayed effects on the reproductive organs, for example, range from decreased fertility or temporary sterility at about 25 rems to the gonads to permanent sterility at 600 rems or more.

Exposure to high levels of radiation also may produce late effects, those that may not develop until some years after the exposure. These

²Rem: a special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors. The rem represents that quantity of radiation that is equivalent --in biological damage of a specified sort--to 1 rad of 250 kVp X rays.

effects can occur either in the exposed individual alone (somatic effects) or in the offspring of the exposed individual (genetic effects). (The probabilities that late somatic or genetic effects will occur can be estimated from the relationships discussed in the next section.) The principal somatic effects are the induction of leukemia and other forms of cancer. Cataracts also may develop if the lens of the eye receives a heavy dose of X rays, gamma rays, beta particles, or neutrons; neutrons are believed to be particularly damaging. In addition, research on experimental animals indicates that high-level, whole-body irradiation shortens life spans, even when other effects do not appear. Such exposure may somehow accelerate an aging mechanism or it may weaken the body's defense mechanisms, increasing susceptibility to the usual causes of death.

Table 6. Representative dose-effect relationships in human beings for whole-body, acute irradiation*

Nature of Effect	Rads of X of Radiation
Minimal dose detectable by chromosome analysis or other specialized analyses, but not by blood samples	5-25
Minimal dose readily detectable in a specific individual (e.g. one who presents himself as a possible exposure case)	50-75
Minimal dose likely to produce vomiting in about 10% of people so exposed	75-125
Dose likely to produce transient disability and clear blood changes in a majority of people so exposed	150-200
Dose likely to cause death in about 50% of people exposed	300

*Source: (8)

LOW-LEVEL EFFECTS As stated earlier, low-level effects have not been observed. Nevertheless, current understanding of the mechanisms of interaction of radiation with biological systems requires that we assume that any level of radiation may be harmful to some degree. That is, we assume that there is no dosage threshold below which no damage occurs. Many have taken for granted that exposure to radiation in addition to the natural background and of the same or lower magnitude represents a risk so small compared with other hazards of life that any associated, nontrivial benefit gained by such exposure would far offset whatever harm resulted from it. But there has been public pressure to estimate the probabilities or frequencies of the effects of such exposure. The argument is that, since any level of radiation may cause some harm and since entire populations of nations or of the world could be exposed to additional low-level radiation, if care is not taken, the extent of the absolute harm could increase even though the damage might not be detectable.

The National Council on Radiation Protection and Measurements (NCRP) (8) has taken the view that estimates of quantitative risk are not useful and has expressed a philosophy as follows:

In particular, it is believed that while exposures of workers and the general population should be kept to the lowest practicable level at all times, the presently permitted exposures represent a level of risk so small compared with other hazards of life, that such approbation will be achieved when the informed public review process is completed.

The BBIR committee of the National Academy of Sciences-National Research Council (7) decided, however, that there was an advantage in considering quantitative risk estimates, despite the recognized uncertainties in the data and calculations. The overall numerical values from the BBIR report can be summarized as follows:

1. It is estimated that exposure of the parents to 170 mrem per year (or 5 rem over the 30 years of the usual reproduction period) would cause in the first generation between about 150 and 3600 serious genetic disabilities per year in the US population, based on 3.6 million births per year.

2. It is estimated that the same exposure of the US population as above could cause from roughly 3000 to roughly 15,000 deaths from cancer annually, with 6000 being the most likely number. (Could is used in the preceding sentence because many scientists feel that as a result of the efficiency of the body's repair mechanisms at the very low dose rates involved, the true effects might approach zero production of cancer.)

The above numerical values are in essential agreement with those reported by the International Commission on Radiological Protection (10) and the United Nations Scientific Committee on the Effects of Atomic Radiation (11). The latter report stresses that the risk estimates are valid only for the doses at which they have been estimated (high levels), whereas the BEIR report suggests that the values are useful as upper-limit estimates in assessment of effects at low levels. A recent NCRP report (9) discusses this matter critically and concludes that the BEIR values have such a high probability of overestimating the actual risk that they are of only marginal value, if any, for purposes of realistic risk-benefit evaluation. At this time, we judge the consensus to be that the BEIR values are most likely overestimates by a considerable margin, but if used with that understanding, then there are important comparisons that can be made.

OTHER ISSUES There are several issues of public concern, some of which involve technical solutions and others that are more related to institutional and sociological factors. Many of these are discussed elsewhere in this volume. It is our intention only to comment briefly on accidents because the risks can usefully be compared to those already discussed and on plutonium because the biomedical aspects have not been generally appreciated.

Accidents The basic document in regard to reactor accidents is the "Rasmussen Report" (29), the final version of which has not yet been published. It attempts to predict the probabilities and consequences of a total spectrum of conceivable reactor accidents. Critical reviews of this report have been made by the American Physical Society (30) and the Union of Concerned Scientists (31). The essence of these analyses is that the Rasmussen estimates would have to be low by 3-5 orders of magnitude in order for the risks from catastrophic accidents to be comparable to those from normal operations of the coal, oil, or nuclear fuel cycles (see Table 7). It is a matter of conjecture whether the public would accept the probability, although very small, of a single nuclear event causing an immediate loss of hundreds of lives as preferable to or in place of the loss of a larger number of lives from fossil fuel combustion occurring in dribblets and therefore unnoticed.

Table 7 Summary of implications of quantitative assessments of health effects in the general population associated with electricity production (all values rounded)

		Coal and Oil	Natural Gas	Nuclear
Premature deaths/year/1000-MWe plant		2-100	0	0.01-0.2
Added risk/year*		1 in 10,000	0	1 in 5,000,000
Age	Normal risk of death/yr	Enhanced risk of death per year because of electricity production*		
10	1 in 3800	1.38 in 3800 ^b	1 in 3800	1.0008 in 3800
25	1 in 700	1.07 in 700 ^b	1 in 700	1.0001 in 700
45	1 in 200	1.02 in 200 ^b	1 in 200	1.00004 in 200
65	1 in 40	1.004 in 40	1 in 40	1.000008 in 40
All ages	1 in 100	1.01 in 100	1 in 100	1.00002 in 100
Number of premature deaths in 30 years associated with routine operation of 300 plants*		20,000 to 1,000,000	0	100 to 2,000
Number of deaths statistically predicted from catastrophic accidents in 30 years from 300 plants [Rasmussen estimate (29)] ^d		—	—	10

* Upper estimates.

^b These estimates are undoubtedly quite high because premature deaths from fossil fuel combustion products fall almost exclusively in the older age groups.

^c This represents the total operation for a generation of power plants that would supply about 300 million people.

^d Based on 1 chance in 10⁶ of an accident per reactor-year causing 1000 immediate and delayed casualties.

Plutonium Of all the radionuclides involved in the nuclear fuel cycle, plutonium has aroused the greatest public concern in regard to potential hazard. A great deal of experimental work has been done over the years on the biological effects of plutonium (32,33); but of course as with other toxic substances it is not possible to predict precisely the effects of low levels in the range of exposure that would produce undetectable effects.

Following is a discussion of those factors that tend to cause plutonium-239 to be hazardous, and then of those that tend to reduce its hazard. Plutonium, as any alpha-emitting radionuclide, is very biologically effective in producing cancer when it is located within the body in direct contact with living tissue. When it is inhaled it comes into direct contact with living tissue, and when it enters the blood it is deposited in such tissues as bone, liver, and lymph node; once deposited it remains for a long time during which it irradiates the tissue. Because of its long physical half-life (24,300 years) it must be regarded essentially as a permanent contaminant just as are many other stable industrial chemicals that pollute the biosphere.

Because alpha radiation will not even penetrate the dead layer of skin, plutonium is not a hazard when it exists outside of the body. Contrary to popular conception, plutonium when swallowed remains essentially outside the body because it is extremely poorly absorbed, does not enter the bloodstream in significant proportions, and being mixed with intestinal contents does not irradiate the surface of the intestines as it passes through the gastrointestinal tract. Plutonium does not become concentrated in the food chain. These characteristics result in large part from the low solubility of plutonium in water and biological

fluids and its tendency to remain fixed in soil.

It appears that inhalation of plutonium is the most hazardous route of exposure. Because plutonium deposited in the lung may be present as small particles, a question has been raised as to whether a given amount of such radioactivity deposited in the lung would be more hazardous if present as small particles rather than being uniformly deposited. This is presently a matter of controversy. One group of workers (34) claims on the basis of theoretical considerations that small particles would be more hazardous (hot particle theory) and therefore that existing standards, which are based on uniform distribution, should be made more stringent. Other workers and several official groups claim that experimental data support existing concepts and that there is no reason for any drastic change of standards (35-38).

The problem of malevolent use of plutonium cannot be logically assessed; this matter has been discussed by Cohen (39). It appears that except for an unreasoning widespread public fear, terroristic purposes could be much more readily achieved by using other more easily available chemical or biological agents.

In general it can be stated that plutonium when inhaled is a toxic carcinogen and great care should be taken to prevent its access to the biosphere. Essentially none would be released from normal operation of the nuclear fuel cycle. Estimates of risks from it as a component of nuclear fuel cycles and the experience of the past 30 years indicate that they are lower than from other parts of the cycle and from other fuel systems.

DISCUSSION AND CONCLUSIONS

Certain qualitative conclusions seem justified. Occupational deaths from the use of coal are considerably greater than for the three other classes of fuel. The explanation for this is undoubtedly the very large volume of mass that must be physically extracted from the earth and the attendant risks associated with underground work. Although the extraction of ore is also required for nuclear fuel, the volume required, and therefore the labor required, is approximately 25 times smaller for nuclear fuel than for coal.

Premature deaths among the general public are very much more likely to result from the use of coal and oil than from natural gas or nuclear fuel. The reason for this is that the use of coal and oil causes very large releases of combustion gases and particulates that cannot practically be contained, whereas releases from gas combustion are small and radioactive releases from nuclear plants are relatively insignificant.

A summary of the implications of the quantitative assessments is presented in Table 7 using upper estimates and rounding all values.³ It is noted that for nuclear fuel the added risk of death per year among the general population from electricity production is less than 0.1% (e.g. 1.0008 in 3800 compared to 1 in 3800 for 10-year-olds). For coal and oil the added risk using upper estimates appears greater (e.g. 2% at age 45), but the values for the younger age groups are undoubtedly lower than those given because no account was taken of the fact that premature deaths from fossil fuel combustion products fall heavily in the older age

³The estimated values of enhanced risk are calculated for illustrative purposes of comparison. They do not take into account age distribution of deaths associated with the processes dealt with and other factors and therefore should be used with care in any further calculations.

groups. In addition to risks, values illustrative of absolute numbers of premature deaths are predicted for the operation of 300 plants for their typical lifetime of 30 years. For nuclear effects to be comparable to those of coal and oil the upper estimates would have to be in error by a factor of about 500, with coal and oil effects having been overestimated or correctable by improved technology and/or nuclear effects having been underestimated. The issues have recently been raised of population exposures from ^{14}C (40) produced in nuclear reactions and from radon-222 (41) from uranium mill tailings. The magnitude of these exposures and the fact that ample time is available to mitigate them if they do turn out to be important problems indicate that they would have no significant impact on the general relationships as presented.

The Rasmussen estimates of premature deaths from catastrophic nuclear accidents would have to have been underestimated by factors of 200 or 100,000 to be comparable to the upper estimates of effects of routine operations of nuclear or coal and oil systems, respectively. It should be noted that of the ten statistical deaths from catastrophic accidents, one represents immediate fatalities and nine represent delayed cancer and genetic effects.

Because of the uncertainties in the upper estimates for coal and oil it is concluded that such analyses are of little help in decision-making in a cost-effective manner for control processes or fuel selection in coal-burning plants. It is clear that large-scale expensive research to provide such evidence is justified. In our judgment, however, a satisfactory estimation of risks to health from coal and oil combustion is not likely to be available for many years because of the enormous complexity of dealing with the effects and interactions of the many chemical agents released.

Despite the uncertainties in the numerical values, they are of interest as a starting point in thinking about what risks society is willing or not willing to accept in order to avoid the acknowledged technical difficulties of handling nuclear power and the chance of catastrophe, or to avoid the biological risks of inadequate electricity.

NOTE ADDED IN PROOF

The final version of the Rasmussen report (29) is now available and is cited as follows: US Nuclear Regulatory Commission, 1975, Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Executive Summary. Rep. No. WASH-1400 (NURBG-75/014), Washington DC: US NRC.

The numerical values used in the text of this article differ from those quoted in the final version but not enough to change the sense of the comparisons made.

ACKNOWLEDGMENT

Appreciation is expressed to Dr. Ronald Wyzga for valuable assistance in the collection and interpretation of the quantitative data.

LITERATURE CITED

1. National Academy of Sciences/National Academy of Engineering, Environmental Studies Board; Committee for the Working Conference on Principles of Protocols for Evaluating Chemicals in the Environment; National Research Council, Committee on Toxicology. 1975. *Principles for Evaluating Chemicals in the Environment*. Washington DC: Nat. Acad. Sci.
2. National Academy of Sciences/National Research Council, Assembly of Life Sciences. 1973. *Proceedings of the Conference on Health Effects of Air Pollution*. Prepared for Committee on Public Works, US Senate, Serial No. 93-15
3. National Academy of Sciences/National Academy of Engineering/National Research Council, Commission on Natural Resources. 1975. *Air Quality and Stationary Source Emission Control*. Prepared for Committee on Public Works, US Senate, Serial No. 94-4
4. National Academy of Sciences/National Academy of Engineering, Coordinating Committee on Air Quality Studies. 1974. *Air Quality and Automobile Emission Control*. Prepared for Committee on Public Works, US Senate, Serial No. 93-24
5. Electric Power Research Institute. 1975. *Conference Proceedings: Workshop on Health Effects of Fossil Fuel Combustion Products*. Rep. No. EPRI SR-11. Palo Alto, Calif: EPRI
6. Goldsmith, J. R., Friberg, L. 1976. Impact of air pollution on human health. In *On Air Pollution: A Comprehensive Treatise*, ed. A. C. Stern, Chap. 16. New York: Academic. 3rd., in preparation
7. National Academy of Sciences/National Research Council, Division of Medical Sciences, Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR). 1972. *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation*. Washington DC: Nat. Acad. Sci./Nat. Res. Council
8. National Council on Radiation Protection and Measurements. 1971. *Basic Radiation Protection Criteria*. NCRP Rep. No. 39. Washington DC: Nat. Council Radiat. Prot. Meas.
9. National Council on Radiation Protection and Measurements. 1975. *Review of the Current State of Radiation Protection Philosophy*. NCRP. Rep. No. 43. Washington DC: Nat. Council Radiat. Prot. Meas.
10. International Commission on Radiological Protection. 1969. *Radiosensitivity and Spatial Distribution of Dose*. ICRP Publ. No. 14. Oxford: Pergamon
11. United Nations Scientific Committee on the Effects of Atomic Radiation. 1972. *Ionizing Radiation: Levels and Effects*. New York: United Nations
12. National Academy of Engineering, Committee on Public Engineering Policy. 1972. *Perspectives on Benefit-Risk Decision Making*. Report of a Colloquium, April 26-27, 1971. Washington DC: Nat. Acad. Eng.
13. Starr, C. 1969. Social benefits versus technological risk. *Science* 165:1232-38
14. US Department of Commerce, Bureau of the Census. 1972. *Statistical Abstract of the United States*. 93rd ed. Washington DC: GPO
15. Argonne National Laboratory. 1973. *A Study of Social Costs for Alternative Means of Electrical Power Generation for 1980 and 1990*. Argonne, Ill: Argonne Nat. Lab.
16. Battelle Memorial Institute. 1973. *Environmental Considerations in Future Energy Growth*. Columbus, Ohio: Battelle Mem. Inst.
17. Hamilton, L. D., ed. 1974. *The Health and Environmental Effects of Electricity Generation—A Preliminary Report*. Upton, NY: Brookhaven Nat. Lab.
18. Council on Environmental Quality. 1973. *Energy and the Environment: Electric Power*. Washington DC: GPO
19. Lave, L. B., Freeburg, L. C. 1973. Health effects of electricity generation from coal, oil, and nuclear fuel. *Nat. Saf.* 14:409-28
20. Sagan, L. A. 1972. Human costs of nuclear power. *Science* 177:487-93
21. Sagan, L. A. 1974. Health costs associated with the mining, transport, and combustion of coal in the steam-electric industry. *Nature* 250:107-11
22. US Atomic Energy Commission. 1974. *Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy*. Rep. No. WASH-1224. Washington DC: US AEC
23. Amdur, M. O. 1957. The influence of aerosols upon the respiratory response of guinea pigs to sulfur dioxide. *Am. Ind. Hyg. Assoc. J.* 18:149-55
24. Amdur, M. O. 1959. The physiological response of guinea pigs to atmospheric pollutants. *Int. J. Air Pollut.* 1:170-83
25. Amdur, M. O., Underhill, D. W. 1968. The effect of various aerosols on the response of guinea pigs to sulfur dioxide. *Arch. Environ. Health* 16:460-68
26. Amdur, M. O., Corn, M. 1963. The irritant potency of zinc ammonium sulfate of different particle sizes. *Am. Ind. Hyg. Assoc. J.* 24:326-33
27. Amdur, M. O. 1971. Aerosols formed by oxidation of sulfur dioxide: review of their toxicology. *Arch. Environ. Health* 23:459-68
28. US Environmental Protection Agency. 1974. *A Report from CHESS 1970-1971*. Rep. No. 650/1-74-004, ORD, NERC/RTP, Research Triangle Park, NC: US EPA
29. US Atomic Energy Commission. 1974. *An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*. Rep. No. WASH-1400, draft. Washington DC: US AEC
30. American Physical Society. 1975. Report to the American Physical Society by the study group on light-water reactor safety. *Rev. Mod. Phys. Suppl.*, Vol. 47
31. Sierra Club/Union of Concerned Scientists, Joint Review Committee. 1974. *Preliminary Review of the AEC Reactor Safety Study*. Cambridge, Mass: Union of Concerned Scientists
32. Stannard, J. N. 1973. Biomedical aspects of plutonium (discovery, development, projections). In *Uranium, Plutonium, Transplutonic Elements*. New York: Springer Verlag
33. US Atomic Energy Commission. 1974. *Plutonium and Other Transuranium Elements: Sources, Environmental Distribution and Biomedical Effects*. Rep. No. WASH-1359. Washington DC: US AEC
34. Tamplin, A. R., Cochran, T. B. 1974. *Radiation Standards for Hot Particles: A Report on the Inadequacy of Existing Radiation Protection Standards Related to Internal Exposure of Man to Insoluble Particles of Plutonium and Other Alpha-Emitting Hot Particles*. Washington, DC: Nat. Resour. Def. Council
35. Medical Research Council. 1975. *The Toxicity of Plutonium*. London: HMSO
36. Bair, W. J., Richmond, C. R., Wachholz, B. W. 1974. *A Radiobiological Assessment of the Spatial Distribution of Radiation Dose from Inhaled Plutonium*. Rep. No. WASH-1320. Washington DC: US AEC
37. National Council on Radiation Protection and Measurements, Ad Hoc Committee on Hot Particles. 1975. *Alpha Emitting Particles in the Lung*. NCRP Rep. No. 46. Washington DC: Nat. Council Radiat. Prot. Meas.
38. Sanders, C. L., Dagle, G. E. 1974. Studies of pulmonary carcinogenesis in rodents following inhalation of transuranic compounds. *Symposium on Experimental Lung Cancer, Carcinogenesis and Bioassays*, June 23-26, 1974, Battelle Seattle Research Center, Seattle, Wash.
39. Cohen, B. L. 1975. *The Hazards in Plutonium Dispersal*. Oak Ridge, Tenn: Inst. for Energy Analysis
40. Magno, P. J., Nelson, C. B., Ellet, W. H. 1975. A consideration of the significance of carbon-14 discharges from the nuclear power industry. *Proc. 13th AEC Air Cleaning Conf.* August 12-15, 1974, Vol. I, CONF 740807, UC-70
41. US Environmental Protection Agency. 1973. *Environmental Analysis of the Uranium Fuel Cycle*. Pt. I (303-B), Fuel Supply; Pt. II (303-C), Nuclear Power Reactors; Pt. III (303-D), Nuclear Fuel Processing. EPA Rep. No. 520/9-73-003 A-D. Washington DC: US EPA

RISK AND INSURANCE CONSIDERATIONS - ENERGY FOR TOMORROW

By
BARLE V. MAYNARD

President
Barle Maynard and Company
Insurance Brokers
100 Bush Street
San Francisco, California 94104

634

RISK AND INSURANCE CONSIDERATIONS - ENERGY FOR TOMORROW

It is a pleasure to be in Tempe to talk with you about the management of risk as it relates to the production of energy to keep America alive and progressive.

During these next few minutes, I will be addressing myself to the matter of risk of loss and the handling of this risk for nuclear, coal, oil, natural gas, LNG, geothermal, solar and wind.

How and where will these energy sources be used? We can hardly move, of course, without the utilization of energy in one form or another. However, the principal areas of use are:

- 1) Generation of Electricity
- 2) Industrial Power
- 3) Automotive Power
- 4) Aircraft Propulsion
- 5) Ship Propulsion
- 6) Domestic Use

In order to assess the relative importance of the various forms of energy it is noteworthy that the power sources are estimated to be:

	<u>1976</u>	<u>1986</u>
Nuclear	8.5%	30.0%
Coal	45.9%	50.0%
Oil	18.0%	16.0%
Natural Gas	17.0%	.5%
LNG	.01%	.5%
Geothermal	.01%	.05%
Solar	0%	0%
Wind	0%	0%
Hydro	12.0%	3.0%

Separate source figures for automotive power, aircraft propulsion and ship propulsion have been unavailable to me. For practical purposes, industrial and domestic uses are included in the above.

How is risk measured? The corollary of this is: How is the consequence of risk measured? The most traditional manner of measuring risk is often "experience". "Experience", however, may or may not be a measure of the risk in future activity. Let me give you an illustration of this. We have had a system along the waterfront in America subject to admiralty jurisdiction but with the workers not on "articles" and thusly falling under the Longshoremen and Harbor Workers' Compensation Act. Principally these have been stevedores

but in the same area there have been many others subject to the Act - ship repairers, sand-blasters, tank cleaners, line tenders, etc., all of whom are directly involved at the waterfront. In addition to this, there have been those falling under the Defense Bases Act, i.e., in foreign service wherein there exists no State jurisdiction and where it is recognized that some U. S. Workmen's Compensation benefits should be available for civilian employees. Thusly, the Longshoremen and Harbor Workers' Act was made applicable as a jurisdictional matter.

Without resorting to a delineation of lost time accidents per million hours of work which has steadily improved through the engineering imposed by the United States Department of Labor and other engineering facilities, we have had some extraordinary differences in insurance rates for the risk. These would appear to be the same on its fact. A characteristic stevedore rate to cover the Longshore exposure in 1970 in the Port of Philadelphia was said to be \$35,000, in Houston \$20,000, in Norfolk \$10,000, in New York \$20,000 and in San Francisco \$12,000. This is the Workmen's Compensation rate for men doing the identical work, being compensated under the same Workmen's Compensation Act. Why the difference?

At that time, the "Ryan" type liability was possible. Irrespective of the preamble to the Longshoremen and Harbor Workers' Compensation Act, there was a judicial circumvention of the expressed intention of the Act. The Act was expressly the exclusive remedy of an injured workman. Suits at law were permitted against the vessel for unseaworthiness. The stevedore was then impleaded in a "liability over" action. Lawyers were more militant in one Port as contrasted with another Port and losses developed in the respective Ports to justify the differences in premium.

In 1973, the Act was revised and the unseaworthiness suits were eliminated. We had many rates developing at \$7.00 and \$8.00 per \$100 of payroll under the Longshore Act.

Here is 1976, following a trend that started in 1975, we have virtually no private insurance market for Longshore risks. A National Assigned Risk Pool has been formed and the rates in this Pool run up to \$36.00 per \$100 of payroll. What happened? Medical fee schedules have gone up. The insurance industry awakened to the fact that there is an open-ended pension provision in the new Act. And it was found that the pension would be paid out in future dollars and not today's dollars.

Obviously the experience of the past would be inappropriate to ascertain the economic consequences of future losses insofar as the Longshoremen and Harbor Workers' Compensation Act is concerned.

In addition to this problem of changed benefits, there is no accumulation of losses and/or injuries under the Longshoremen and Harbor Workers' Compensation Act. The States

accumulate this statistical data with respect to losses under the State Workmen's Compensation Acts. Thusly, although the man hours of losses may be much the same as distinguished from the economic consequences, still the statistical data is not available as an industry matter and, thusly, much of the assessment of the risk must be done in a judgemental fashion without benefit of statistical support.

Within the insurance industry the U.S. approach for measuring risks is quite different than the London approach. Because of our great fear of restraints of trade, the insurance companies are required to be totally competitive in their rate making effort. The anomaly is that Workmen's Compensation rates are established through governmental agencies on an industry basis and certain data is permitted to be accumulated through the Fire Rating Bureaus.

The London underwriters at Lloyd's operate under a theory of concentration of underwriting disciplines in a limited number of syndicates and with a limited number of Lloyd's underwriters. The historical statistics on losses are accumulated with those leads. Once a reputation has been established on the part of some individual or individuals underwriting a given risk, the participation by other Lloyd's underwriters follows.

By contrast within the American system, there is an accumulation of data (exclusive of the Bureaus and Associations) in the offices of each underwriter (insurance company) to the exclusion of other underwriters.

The matter of risk measurement becomes more judgemental with respect to an emerging risk in a new field or in a field that is sufficiently at variance with the history of yesterday so that it must be treated as a new risk.

Whether underwriting has a statistical or judgemental basis, or a combination of both, if insured it finds its way to a profit and loss statement by way of a premium. If not insured, it finds its way to the financial statement as a pure loss.

I will next give you my views as to the risks of the various energy sources to contrast one with the other. We can then address how these risks of loss are being addressed.

Aside from the historical data available as to losses, attempts have been made to extrapolate from other industries and other activities as well as from past experiences. For instance, in the aircraft industry the statistics are available relating to pilot error, equipment failure, etc. This loss data, of course, prior to the 747 related to the smaller craft. Extrapolation was made from that statistic to the 747 to forecast loss expectancy for the 747.

A more scientific approach to loss expectancy was developed within the space industry to forecast more accurately the need for redundant back-up systems for the landing of a

man on the moon. This was the fault tree concept which was ultimately adopted by Professor Rasmussen of Massachusetts Institute of Technology in the preparation of his WASH 1400, the loss analysis for the Nuclear industry.

There follows an extract from the draft summary report, Reactor Safety Study (WASH 1400) (August 1974):

"The Reactor Safety Study was sponsored by the U. S. Atomic Energy Commission to estimate the public risks that could be involved in potential accidents in commercial nuclear power plants of the type now in use. It was performed under the independent direction of Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. The risks had to be estimated, rather than measured, because although there are about 50 such plants now operating, there have been no nuclear accidents to date. The methods used to develop these estimates are based on those developed by the Department of Defense and the National Aeronautics and Space Administration in the last 10 years."

"The objective of the study was to make a realistic estimate of these risks and to compare them with non-nuclear risks to which our society and its individuals are already exposed. This information will be of help in determining the future use of nuclear power as a source of electricity."

The following data may illustrate some of the differences in risk.

Annual fatalities and injuries expected among the 15 million people living within 25 miles of U. S. Nuclear Reactor sites:

<u>Accident Type</u>	<u>Fatalities</u>	<u>Injuries</u>
Automobile	4,200	375,000
Falls	1,500	75,000
Fire	560	22,000
Electrocution	90	
Lightning	9	
Reactors (100 plants)	2	20

The hazards of fatalities and/or injuries in coal mining are approximately 25 times that of uranium mining.

AVERAGE PROBABILITY OF MAJOR MAN-CAUSED AND NATURAL EVENTS

<u>Type of Event</u>	<u>Probability of 100 or more Fatalities</u>	<u>Probability of 1000 or more Fatalities</u>
<u>Man-caused</u>		
Airplane crash	1 in 2 years	1 in 2000 years
Fire	1 in 7 years	1 in 200 years
Explosion	1 in 16 years	1 in 120 years
Toxic Gas	1 in 100 years	1 in 1000 years
<u>Natural</u>		
Tornado	1 in 5 years	Very Small
Hurricane	1 in 5 years	1 in 25 years
Earthquake	1 in 20 years	1 in 50 years
Meteorite Impact	1 in 100,000 years	1 in 1,000,000 years
<u>Reactors</u>		
100 Plants	1 in 100,000 years	1 in 1,000,000 years

OCCUPATIONAL HEALTH AND SAFETY OF ELECTRIC POWER PLANTS

	<u>Coal</u>	<u>Oil</u>	<u>Natural Gas</u>	<u>Nuclear</u>
Occupational Health (Man days lost per year)	600	Unknown	Unknown	480
Occupational Safety				
Fatalities (Deaths/Year)	1.1-4	0.17-0.35	0.08-0.2	0.1-0.15
Nonfatal Injuries (Number/Year)	46.8	13.1	5.3	6.0-7.0
Total Man Days Lost Per Year	3770 ^A - 9250 ^B	1725- 3600	780- 1990	270- 1000

- A. Surface strip-mined coal.
B. Deep-mined coal.

PUBLIC HEALTH EFFECTS FROM COAL, OIL, AND NUCLEAR POWER PLANTS

<u>Plant Type</u>	<u>Pollutant</u>	<u>Relative Hazard Index^A</u>
Coal	Sulfur Dioxide	32,000
	Particulates	1,000
	Nitrogen Oxides	4,530
Oil	Sulfur Dioxide	11,960
	Particulates	176
	Nitrogen Oxides	4,450
Nuclear Pressurized Water Reactor	Krypton-85 & Xenon-133	1
	Iodine-131	19
Boiling Water Reactor	Short-lived Noble Gases	800
	Iodine-131	850

- A. As an example, a relative hazards index of 4,450 from the nitrogen oxides emitted from an oil-fired plant means that the nitrogen oxide emissions from an oil-fired plant should have 4,450 times the public health impact of the Krypton-85 Xenon-133 emissions from the same sized nuclear plant.

How Should the Risk be Handled

With the risk somewhat in mind, the final area of discussion is as to how this risk should be handled. Always, the first consideration is to, if possible, eliminate the risk of loss. There was a time when the public was so unconcerned about working conditions, risks to the public, etc. very little thought was given to this aspect of risk management. As a matter of fact, it was rare indeed that there was any effort on the part of government or industry to reduce the risk.

Nothing illustrates more effectively to me the value of safety engineering than the old statistic of steel erection wherein it was anticipated that there would be one death per floor in the erection of the steel for a high rise building. I was involved as an insurance broker with the erection of the steel for the Fairmont Tower in San Francisco in approximately 1960. There was not a single lost time accident in this 25 story steel erection project. This was a goal that had been established by Bethlehem Steel. It is also noteworthy that because of the safety engineering practices established by Bethlehem Steel the in-house charges for Workmen's Compensation Insurance under their self-insured program was but a fraction of the industry standards charged

under the National Bureau and the State of California rules, a further indication of the economic value of appropriate safety engineering.

We know that Fire Engineering substantially reduces the expectation of fire losses. It isn't merely the matter of appropriate sprinklering and dry chemicals. Building materials, fire walls, fire alarms, fire brigades, fire fighting equipment, etc., also increase the expectation of reduction of risk.

In Products Liability cases appropriate quality assurance procedures, recordation of manufacturing procedures and processes, research and development, etc., have a very material impact on the expectation of loss in this area.

Driver training courses and other areas of employee training are significant in reducing losses.

Improved agricultural seed strains, the availability of irrigation, mechanization for more expeditious harvesting when weather patterns are more critical and short lived, more scientific feeding in feedlot - all of these and more go to reducing the farmer's risk of loss.

The utilization of modern day accounting practices including inventory auditing, spot audits and procedural audits have impacted to reduce fidelity - employee dishonesty losses, business interruption losses and have assisted in the measurement of risk.

Of course, modern medicine and the research and development that has accompanied modern medicine has not only given us an awareness as to the cure of disease, but as to the cause of disease and consequently the ability to take steps in industrial areas to reduce the causes of sickness and disease. These factors may be categorized as engineering devices for the reduction of losses. Irrespective of the efforts made to minimize these losses, there are residual normal risks in living. Acceptance of risks varies greatly from one activity to the other. Acceptance of one risk is not material in the acceptance of other risks. The acceptance of risk by the public is quite different than the acceptance of risk by scientists and the business man.

As a businessman, consideration must be given to the financial strength of the business entity itself. A small under-financed concern handles and should handle risks quite differently than a large industrial establishment. A general rule is that where there is frequency of loss of recognizable magnitude to re-occur in the regular course of business, these items should be expensed out on a daily basis without effort to transfer the risk or to defer the expense. One of the best examples is losses that would normally fall under our Workmen's Compensation Act. With a large volume of employees worker's injuries are certain, industry averages for anticipated losses are clearly available. In-house

engineering and claims handling can be established and the losses taken into the normal charges of the business operation. Yet, even with the larger business institutions, it might be that losses are generated from other States through satellite operations and because of the lack of size it would be well to transfer this risk to an insurance company.

With a hypothetical Workmen's Compensation risk it might be in a medium sized firm that it is felt that the whole of the risk should not be assumed and only that required by statute should be assumed. In California under a self-insured program only the first \$25,000 of any one loss need be assumed and it might be advantageous to transfer a part or all of the excess to an insurance company to avoid a catastrophic result and, thusly, a dislocation of profits in any given period.

The concept of deductibles in Public Liability policies and Physical Damage policies follows the same general concept. The utilization of deductibles, in-house engineering to be accompanied by employed engineering, that is from the insurance company or retained professionals, should all be considered in the assessment of an appropriate program.

Very often it happens that a business entity will self-insure a Workmen's Compensation program due to the concentration of employees. Yet other forms of risk may be insured to buy claims and/or engineering service. Examples of this are: Automobile and General Liability risks, Boiler and Machinery risks and Ocean Cargo risks. Claims may arise in other jurisdictions with a need for claims servicing. This is equally true of engineering.

A business entity may make a determination that losses may be certain but may occur over a longer period of time than a single accounting period. Thusly, an effort might be made to level the losses over a number of accounting periods rather than taking those losses in a single accounting period; yet there may be a disinclination to transfer any part of the loss to an insurance company. This is often handled through the concept of a Captive Insurance Company or the Spread Loss concept. As to the Captive problem, consideration should be given to the tax aspects and the affect of offshore captives vs. Colorado captives. Associations including other firms may join in spreading risks. Parts of risks may be handled by commercial insurance and other parts may be spread in captives or "spread loss" programs.

Risk of loss may be due to obsolescence, changing technology environmental impact, mechanization (which is a change in technology), change in demand, political imbalance, devaluation or non-convertibility of currencies. Risks may result from continuing expense with no corresponding income to cover the continuing expense. Risks may result from the nature of the process, the substances handled, the people involved, the geography, the topography, the climate, the environment, etc.

Each of the energy sources has its own risks of loss with its own impact on profits, rate make-up, public acceptance, etc. - always the handling of these risks is done in a comparative way.

Why should the problems of risk management and insurance differ to any great extent from the problems of yesterday. Let me illustrate by recounting my experience with a couple of generating stations. Some years ago, I put together an insurance program for the Karad Dam in Iran, which at that time was one of the great engineering achievements of the world and now supplies much of the electricity for Teheran. I put together a quota-share Builders Risk policy in the amount of \$40,000,000 which was a very large placement at that time. You contrast that with the exposures at San Onofre 2 and 3, the nuclear stations being constructed by Southern California Edison. Each of these stations, side by side, is now costing around a billion dollars. Insurance available for the Builders Risk insurance is \$150,000,000 and for the two plants, that also is the amount of insurance that will be available when the two units are completed.

At that time, I arranged for coverage for the movement of the Turbine Generators for Diablo Nuclear Station, the greatest amount of coverage theretofore arranged on a barge shipment was \$25,000,000. We had \$50,000,000 of exposure on the barge for physical damage to the cargo alone, several million dollars on the barge and approximately \$150,000,000 on the time element consideration.

A market has been put together for off-shore drilling platforms for the North Sea with limits of \$200,000,000.

My father was in the farm machinery business. His customers were farmers, contractors, loggers and the builders of that day. I grew up with considerations of dirt moving, log moving, etc. I recall in those childhood days that it was costing a dollar a yard to move dirt for highway work. It now costs pennies a yard because of the vastly increased energy resources available through more sophisticated machinery. One of my college jobs involved paving streets in Salem, Oregon for the City Street Department. We mixed our concrete on the job, moved it in wheel-barrows and leveled and tamped it by hand. Look at the machinery that is now available for highway and roadway construction. This is energy, equipment, improved technology and a changed insurance exposure. There is no reason to believe that this trend will change. We will continue to have increased capacity problems, a continuing need for re-assessment of risk and the same problems of absorption of risk or transference of risk.

I am exceedingly confident that the recently expressed disenchantment with governmental regulation and interference in the private enterprise system will work to permit

a continued self-expression which creates solutions to tomorrow's risk problems, none the least of which will be the growth in capacity within the insurance market. We must be ever vigilant to correct the warped impressions of those who have not had the experience of the dynamics of the self corrective mechanism of the business community and who might like to return to a trend toward the stifling and limiting aspects of governmental regulation. The growth of our free institutions are absolutely imperative if we are to meet these challenges for tomorrow. You people particularly mold tomorrow's actors. I would hope that you would be active participants in stimulating the free economy of America and, thusly, set the stage for meeting tomorrow's challenges.

In closing, I want to thank John McKlveen and his associates for giving me the opportunity of being with you today and participating in your most extraordinary conference.

Thank you.

ENERGY IN PERSPECTIVE

By
DR. NORMAN HILBERRY

College of Engineering (Nuclear)
University of Arizona
Tucson, Arizona 85715

ENERGY IN PERSPECTIVE

Mr. Director and participants of this energy workshop -- I accepted the invitation to speak here with alacrity for I consider that you constitute a uniquely important audience. I have maintained for a long time that if any sort of change is to be made in the status quo of any culture, it has to be accomplished at the level at which you folks work. The junior high school is the level at which we make our scientists and engineers. If you wait until the students get into high school, boy and girl problems and similar societal concerns override intellectual interests. In college, economic and organizational matters begin to dominate. The result is that in many cases student's life interests and career decisions are made right at the point at which you folks meet them. In many respects, you constitute the most important formative influence affecting their choices. Now, this might not have been true when I was a child. Then the family dominated. Now the societal separation between families is less than it was then and the inter-family pressures are greater. Peer influence, always to be reckoned with, has increased still further weakening family influence. As a result, in many instances the teacher carries fully as much weight as the parent today. All of which puts the junior high school teacher in a uniquely important position in my estimation.

I am an ex-physicist working as a nuclear engineer. Clearly, I am biased. This should be made clear on record. I have been in this

nuclear business since December 1941. For a long period of time, I was present at the start-up of every new reactor. I still think the safest place for any single human being to be is on the top of an operating production nuclear reactor. It is the only place I know of where, if a 747 were to lose a motor and if that motor were to come straight down at you, you would be safe because the buildings they put these reactors in have to be designed so that the motor would bounce. When you are in your bedroom, somebody can drive a truck through the wall and kill you but no one is going to drive a truck through any of those buildings in which nuclear reactors are set up. I believe that compared to other hazards we accept without worry, nuclear reactors are exceptionally safe devices. In view of this history, however, while I would like to have you listen to what I say, I would like to make equally sure that you delay accepting my word until you have thought the situation through for yourselves and come to your own conclusions as to its validity.

Before beginning my comments, I would like to say that I think Dr. McKlveen and his committee have done a fantastic job in putting together the content of this conference. I would have liked very much to have been here for the entire workshop, but I simply could not find the time to do so. I did sit down and go clear through the book you have been given. It is an excellent piece of work. It covers essentially the full breadth of the field and it covers it in an authoritative fashion. As a result, your colleagues may well feel that you are now obviously their authorities on energy to whom they can turn for answers to all of their questions.

A somewhat similar situation developed in Chicago. When the Commonwealth Edison Company started to build its Dresden I nuclear power plant, it gave its public information program a high priority. For example, visitors to the plant were planned on from the beginning. While in the control room during my first visit to the plant, I realized that one wall consisted mostly of one-way glass windows. Control room operations could be watched from the other side without disturbing the operators. When asked what it was for, the answer was that the area behind the windows was for visitors to the plant. Visitors could not be allowed to clutter up the operations area so it was decided to build that gallery on. The guides took the visitors up to the gallery through an outside entrance and let them watch what the folks were doing in the operators room. Visitors were allowed only after school hours because the guides were high school science teachers of the region. They were trained in what the plant was all about and they took care of all the visitors.

I went back to the laboratory and we started hiring science teachers for the same purpose. They took over the visitor guidance on special occasions and on Saturdays, in particular. What happened was that these individuals very shortly were serving as advisors on nuclear energy for the entire Chicago school system. I suspect that you had better hang on to your books because I think there will be many of you who will find yourselves in this same dual position. It has its joys and it has its sorrows, it has both compensations and frustrations. I think, however, you may find it fun.

As I went over the papers in your book, it seemed to me that one could describe the situation that we face today succinctly by the

simple statement, "We have an energy problem." I think this is clear. You were treated to a lot of discussion of resources. It is very clear that oil and gas will disappear within a few decades if world populations and world per capita usage continue to grow as they have in the past several decades. At present usage, they will probably disappear within fifty years. They will disappear in the sense that the remaining supplies will be so hard to get and so expensive that they will indeed be reserved for the petro-chemical industry for which they form a very unique and irreplaceable raw material. Coal, considerably more prevalent than oil and gas, could last for several centuries, again depending on how you view the future. Used at the present rate, coal might indeed last for say 2500 years but I defy you to figure out how you are going to keep the use of coal down to the present rate with gas and oil depleted. The chances are that its lifetime will be very much closer to 200-250 years.

You will notice that in each case, oil, gas or coal, what we do is transform the potential energy bound up in the organic molecules of the fossil fuel by combustion into thermal energy. Every time you burn a pound of coal or a gallon of oil, you put an added amount of thermal heat into the terrestrial atmosphere. This has to be radiated out. Otherwise, the temperature goes up. The other big terrestrial energy supplies are the nuclear sources. But here again, both fission and fusion transform part of the potential energy of the atomic nucleus into thermal energy. The more of this we do, the more heat energy we have to radiate into space. The rate at which you can get rid of heat energy by radiation goes as the fourth power of the absolute temperature of the radiating surface, provided the emissivity of that surface

remains constant, as in this case it would probably do at least closely enough. Thus, to radiate more heat means raising the surface temperature.

Shifting now to the potential nuclear resources, fission energy is the one we know how to handle at the moment. I get somewhat exasperated when I read articles that indicate we know little or nothing about breeder reactors because the first reactor to produce any useful electrical energy, certainly in this country, was a breeder reactor. The amount of electrical power it generated was not much but it was enough so that when we operated our laboratory on our own supply and cut loose from the public utility lines we would get immediate phone calls to check that there had been no untoward events. A second much larger experimental breeder reactor has operated reliably and routinely at Idaho for well over ten years. What has not yet been done is to demonstrate a full utility size reactor plant. The present power reactors we use for the generation of electricity are indeed "burners." They burn Uranium-235. The light water cooled reactors convert some U-238 to Pu-239 and burn it; the gas cooled reactors convert some thorium into U-233 and burn it. But mainly they burn U-235. If one looks at this U-235 source of energy, again there would appear to be enough for about 200 years. If you were just to burn Uranium-235 you could keep going for about the same time you could with coal. If you go to the breeder, however, you expand this enormously on two counts. One, you get much more energy from a given amount of uranium because the breeder consumes not only the 0.7% U-235 but practically all of the 99.3% U-238. Thus, the breeder system gives about 100 times as much energy as a burner for a given amount of ore. Now you can use

enormously lower grade materials because at 100 times more energy for a given amount of uranium you can afford to pay almost a hundred times as much for it. The second count increase arises from the fact that the quantities of ore available go up rapidly as the grade, the percentage of uranium in the ore, goes down. Add in the thorium-- U-233 breeders and you are talking about some hundreds of thousands of years that the breeders would be able to supply energy. Incidentally, that uranium reactor that operated 1.8 billion years ago in Africa operated, for as nearly as we can tell, some several hundred thousand years. This is one of the most fascinating of tales. If you have not read about it yet, you ought to do so because this is really a detective story of no mean dimensions. Incidentally, all the plutonium stayed right there and by radioactive decay became uranium-235. You can tell it stayed there because you can tell that the level of uranium-235, atomic percent, is just enough higher to account for the fact that the plutonium had decayed into U-235.

Fusion. We haven't gotten there yet. My own opinion is that we will. I think it's not going to be an overnight deal, having lived through some of these others, finding out what the real nuts and bolts business requires after you once make the scientific feasibility check. If one uses the Deuterium-Tritium reaction, which is the easy one, it turns out that the amount of lithium available to make the tritium required to make the DT reaction operate, is about enough to fuel the reactors for about 250 years at the same energy usage discussed above. Apparently, the architect that set this system up was looking at 250 years, plus or minus. On the other hand, if you go to the DD reaction, which is deuterium fusing with deuterium, and the real energy answer,

then the units you are dealing with are millions of years. There is no question that that supply is plenty.

In every case, however, note that you are transforming potential energy into thermal energy. That means that one is indeed faced with the thermal balance problem. This is the 200th anniversary of the United States. Suppose we take a look at where we will be 200 years from now. Kind of makes your hair stand on end. It's more or less meaningless except that it has a very definite meaning. In 200 years if the world were to continue to increase its energy use at the present rate of five percent per year, and 200 years isn't very long, the mean temperature of the earth would be 168° . That's pretty hot. Actually, using this five percent per year rate, at the end of a hundred years the mean temperature would have gone up about a degree. At one hundred fifty years, it would have gone up about ten degrees, and at the end of the two hundred years, it is up about one hundred degrees. What this says is that you can say all you please about the necessity for continual growth, you are not going to have it with this kind of energy technology because you simply cannot meet that kind of a situation. What it says is that we must find some way of utilizing solar energy because the solar energy is there to be dealt with whether we use it usefully or not. At the present moment, it is 20,000 times as much as the world is using. But when you start in these exponential phenomena 20,000 can vanish in an awful short period of time. Actually, in two hundred and three years the five percent per year increase gives a total increase factor of 20,018. That means that the amount of thermal energy that fossil and nuclear fuels would be putting into the atmosphere would be just equal to the energy the sun is supplying the earth, so it

would be necessary to get rid of twice as much as at present.

Solar energy utilization is clearly an eventual must. The problem is the problem of getting there. Moreover, it is largely a problem of people. A fair amount of the technology we know. The things that are going to have to change are us. We have been living on very cheap energy. A much larger fraction of each individual's effort is going to have to go into supplying him with his energy. The energy that each of us has to live. This is going to hurt because it means that the additional effort we have to put in to getting our energy, we are going to have to take out of something else. The immediate answer of many of the folks I run into is, "We must have conservation." Well, we are going to have conservation whether we want it or not. The sooner we get about it, the better. But never forget conservation has its costs. It is very simple to look solely at things we know as a first tier phenomenon and ignore the second and third and fourth tier effects. We live in an extremely complex system. Upset any one part of it and immediately many other things start changing. Technologies change. Before the Kelvinator there was the "iceman." And with these changes come social changes in many areas. I don't think it's possible for us to anticipate in detail what these changes will be. But I think it is necessary that we anticipate that they will be, and lay the ground work for accepting them and moving into them effectively whatever they may be.

It would seem to me that one of the things that constitutes a very basic problem for us is our lack of realization of how completely our society, in fact, of how entirely human survival itself is tied inescapably to our ability to utilize extrinsic energy resources. In

a paper in the September 1971 issue of Scientific American, Professor Earl Cook, of Texas A&M, discusses this matter and presents the results of his analysis of the archeological and historical data. A brief look at his data is illuminating.

If one examines how mankind evolved to its present state the first thing to notice, of course, is that the human machine is and was quite different from the rest of the animals. There were several factors in its favor. One of these items was the fact that man could eat almost anything. This was important because for many years the human animal had to do just that. It may get to the point in which it will have to do so again. At least the mechanism is there for successfully digesting almost anything. Sometimes, if you travel a lot, you think you have absolute proof of that fact. The second factor was posture. Whatever the reasons may have been the result was that the human animal assumed an erect posture. This freed his arms from locomotion duties and left them available for other use. And such use was inevitable. You go out for a walk today and what happens; the first thing you know you pick up a stick to swing around or a stone to toss or throw. This is not a new phenomenon; it goes way back. And with this freedom of the arms came the full development of the hand. And with the full development of the hand came the possibility of really manipulating the environment in which one lived. The initial development of the hand came as the proto humans tried to survive in the trees. The same environmental constraints led to binocular vision and to color vision so that the creature could use its hands precisely, knowing accurately where things were. There were, of course, a lot of other favorable physiological factors the

crowning item being the human brain. The brain, fortunately, continued to develop as it was needed. Fortunate because if you take a hard look at the rest of the human carcass, marvelous as it is, it is anything but very impressive as a competitor with hungry major carnivores. It is not very strong. Few individuals are able to go out and wrestle alligators or bears. It's impressive, but I don't think many of us would survive very long in that game. We are not strong. The human animal can bite but it does not do a really respectable job compared with a lot of other creatures. Man can't run very well. Almost any animal can out run him. So, early man was really up against it. The primary superiority he possessed to get him out of trouble or to keep him out of it was his brain.

The second thing to notice is that with that background of human strengths and weaknesses what essentially enabled mankind to pull through so far are some compensating skills that it developed.

The first was organization. Organization enabled a group of people to amplify its effectiveness. Let a group of people work without direction and their effort is likely to be totally wasted. Their output lacks any semblance of coherence. The probability of enhancement of effort due to group action is small indeed. As soon as the group begins organizing its efforts, so that each individual plays a definite part in what needs to be done, the effectiveness of the operation goes up orders of magnitude. But in order to achieve organized action language had to be invented. Fortunately, the brain had developed a center which enabled mankind to come up with language. This is the big difference, obvious nowadays, between ourselves and the chimpanzees. The chimps simply lack that necessary center in the

cerebrum that enables man to use oral language effectively. The first great human invention was the invention of language.

Second, is the business of tools and devices. With free hands man quickly found out that it was much easier to dig up a root with a stick than it was with his fingernails. As he got good at throwing stones he found he could kill a squirrel a lot easier with a thrown stone than by trying to run it down. He also found that once killed the sharp edge of a broken stone cut it up for eating faster than his teeth could. Machines, devices, tools all increased human capability and made it possible for the human animal to do all sorts of things that other animals could not do.

Finally came the business of the use of extrinsic energy. When man got to the place in which he could utilize other energy sources then individual productivity was amplified enormously. And this is the stage at which we still operate.

If you look back a million years ago (the evidence is pretty good now and continually getting better) one finds that the human animal worked very much as an animal. He spent essentially all his time getting food. The food was eaten where and as it was found. Actually, there have been primitive tribes within the last few years, within this century certainly, that were still operating on this basis of a straight food gathering operation. The per capita energy consumption under those circumstances is about 8,000 BTU. (Note: A standard 8 ounce pyrex measuring cup filled to overflowing holds just under 9 ounces. Fill it with ice water and pour it in a pan on a stove or heater. It will take 100 BTU to heat that water to the boil.) This is what it takes to feed an animal such as the human animal was at that time and

keep it in a good healthy condition. When times were good the human individual got his 8,000 BTU; when things were bad he took what he could get.

Sometime between 1,000,000 and 750,000 years ago man first controlled fire. I keep hearing about the horrors of nuclear energy and cannot help thinking of the first time that one of these crazy human characters came back to the cave carrying a burning branch. Remember people had been wiped out in forest fires just like deer and squirrels and every other animal up to that point and the one thing you did if you saw fire was get away from there as fast as you could. Yet here was this crazy individual coming home carrying a burning branch. It was at that point the human line broke from the rest of the animal kingdom because it was at that point man learned to use extrinsic energy resources. At first, fire probably was used primarily to scare animals off. I wouldn't be at all surprised if that's how the guy learned of its use. Some hungry tiger was out on his trail along the edge of a burned over brush area, he saw a burning branch, picked it up and threw it at the tiger and the tiger left. The message was clear. So he took a burning branch home to keep tigers away from the door. A defense mechanism but once the control was accomplished it did other things. It made it possible for mankind to expand its living quarters into areas that otherwise purely from the climate conditions would have been impossible. And it did still another important thing; that is, it extended the hours of his day. Extended it into a period which he could not go hunting for food so he was faced with a period of time in which he could think and could do things. Tools were one outcome.

Somewhere along after that came cooking. And that was a second great break. Just imagine sitting down to eat and having your hostess serve you a leg of lamb, raw. You have no knives and forks to assist you so you just sit there and gnaw at it. That dinner period isn't going to be over in 30 minutes. You have undertaken a real job. Now if you cook it, then, as Porthos used to demonstrate on much larger joints, you could finish that leg off very much faster. Cooking made it possible to accomplish the necessary eating business in a much shorter period of time and expanded enormously the number of things one could eat. It did one other thing; that is, it changed a lot of the organic substance that were present in the raw food into forms that otherwise would be unavailable and provided a much broader dietary base for man to live on.

Things improved ever so slowly over the next 45,000 human generations, some 100,000 years culminating finally in the peak of the hunting culture. If you examine the human society 100,000 years ago, you will find that the utilization of energy per capita, in the best of the hunting cultures, was about 20,000 BTU per person per day. The food use had gone up to about 12,000 BTU and about 8,000 BTU was now being used for domestic purposes - heating, cooking, chasing off the tigers and so on and so forth. Mankind was still living on the bounty that Nature provided but nonetheless, living level and survival security had both improved. Food intake increasing from 8,000 BTU to 12,000 BTU represented a change from a diet based largely on grain to one consisting largely of meat. An animal is not a very efficient converter of energy. You have to feed an animal about 10 times as many grain BTU's as the animal carcass will provide in food BTU's for eating. We still have

this problem to face. It follows all the way down through the years - the more our diet is made up of meat, the bigger our take in energy has to be at the grain feeding line in order to supply it.

The next change came along about 8000 B.C. after another 4,500 human generations or some 90,000 years. This is the time when man first made a positive move to control his environment. That move was the shift from hunting and collecting to animal husbandry and agriculture. Man is now purposefully utilizing solar energy - he is manipulating it. With this change, all sort of things happened. In the first place, the actual energy consumption went up to about 48,000 BTU per person per day. An individual used about 16,000 BTU for food per day, about 16,000 BTU for domestic purposes and industrial activities began using some 16,000 BTU per day. What happened was that now the average individual is raising a surplus of food. This is the reason that everyone is in better material position. It frees mankind from periodically recurring want because the food that is not immediately needed can be stored for future use. But where and how is it going to be stored? It meant that man had to invent and implement ways of storing the food. He had also to invent and make tools to raise the food and care for the animals. Industrial activities had begun. Human life was assured in a sense that it had never been assured up to that time. But these same changes guaranteed slavery. Up to that point, an enemy captured was best off dead, otherwise he consumed part of your patrimony. He was not necessarily eaten but at least the victor saw to it that the vanquished devoured none of the victor's food. The instant civilization got to the place in which an individual could produce more than he required for his maintenance

slavery was inevitable. And from somewhere around 5000 B.C. to 1500 A.D. the energy source that moved human civilization from the early Tigris-Euphrates and Egyptian cultures through the Greek and Roman periods and on into the early days of Western European civilization was slave labor. This was extrinsic energy to the ruling classes that controlled it. It was necessarily extrinsic as far as the slave was concerned. However, it is also true that in all probability for many the life of the slave was a better life physiologically than he would have had as a free individual in an area in which his livelihood was completely uncertain. Now it was to a master's advantage to see that he was kept in good physical condition.

The next big change started about 1000 A.D., when slavery began to peter out. During the breakup of the Roman Empire and the Dark ages many slave owners could no longer afford to maintain their slaves. The cheapest way of taking care of this problem was to give them their freedom and turn them out on their own resources. The result was that civilization as it had developed began to crumble. Its interdependencies and its supply complexities could not be sustained without a flexibly controllable energy resource. Fragmentation of society ensued. And then new extrinsic energy resources began to develop. For example, it was at this point the water wheel really began to move in. The mines had been pretty well mined out. Water levels were up to a point at which, although there was more mineral there, you couldn't get at it because it lay under the standing water level. Without slave labor to man the pumps mining and the metal industries faced a bleak future. It was then the water wheel came to the industrial fore. Water wheels properly designed were able to lower that water

table and make more mineral available. They could also power the blacksmith's forge bellows and they could mill grain. Their uses and their numbers multiplied. Windmills also came into play. They were ideal for pumping and milling purposes in areas such as Holland and the open wind blown regions of northwest Europe. The horse suddenly became a valuable creature instead of a status symbol. Up to this time, a horse was entirely a light draft or riding animal. You could use him as a status symbol but if you tried to make him do any real work it was doomed to failure. Four men could do more work than one horse and they consumed less grain equivalent. That told the story. But here again technology stepped in. Up to that time, the ox had been the standard draft animal for millennia. But an ox is slow and they can only do some things. One thing he can do is live entirely on grass which a horse can not do and remain healthy. That made him valuable for he did not compete with man for food. But other than that he was a pretty slow business. When you try to put an ox yoke on a horse to use him for draft purposes you choke him seriously. Obviously, you are not going to do any effective pulling under those circumstances. Eventually, somebody recognized the difficulty and invented the horse collar. As soon as that was accomplished, the horse really became a useful extrinsic source of energy. You shoveled fuel into the horse in the way of oats and he shoveled energy out in the way of plowing.

As a result of these changes in energy resources and technology agriculture had a second revolution. In northwestern Europe in the period at about 1450 A.D., the daily per capita energy consumption had gone up markedly as did the productivity. Food consumption had gone

up to 24,000 BTU, the domestic consumption to 48,000 BTU, industry was consuming 28,000 BTU and for the first time, transportation begins to show up using about 4,000 BTU. In other words, an overall total of about 100,000 BTU's consumed per person per day. And with this energy change, came a marked societal change once again. One of the big new metal bladed, deep turning plows that were invented about this time required a number of horses to pull it. The little farmer simply could not afford the plow and enough horses. The result was that co-operative fields began to appear. The group got together and bought a plow and brought their horses to team up to pull. They did a co-operative plowing job and the output went way up. But it went up on a co-op basis. Next, it moved then from its co-op form into what we would now call an agri-business. Agri-business is not a new phenomenon.

At about the time that this second agricultural revolution was well underway, the use of coal as a source of heat was being developed. "Sea coal" had been recognized as a fuel about 1300 A.D., and it was gathered from along the coasts of Britain and France for domestic heating purposes as the supplies of wood dwindled. Eventually, mines were opened and coal became an important energy resource. Then came the development of the steam engine - first for pumping in mines, then for supplying energy for metallurgical processing, then for the chemical industry, and then for the whole range of industrial and commercial affairs. If you plot the log of these energies that I have been talking about against the log of the time back from 2000 A.D. to the period in question, you find that the graph is essentially a straight line from 1,000,000 years back up to about 1450-1500 A.D. It curves sharply there and starting at 1750 A.D. it just takes off again as a straight line

but at an enormously increased rate of growth up to the present time.

During this transition period, the societal changes were as dramatic as were the changes in technology and energy utilization. Industry moved from the control of the craft guilds to the bankers and on to the entrepreneurs. Manufacture moved from the cottage to the sweat shop. Per capita productivity increased explosively. Commerce burgeoned. And class distinctions grew apace.

By 1875, when the industrial revolution reached its peak in Great Britain, the per capita daily energy consumption reached about 300,000 BTU per person per day and by 1970 in the United States, it was 920,000 BTU per person per day. Now the amount of work that you or I could do, physical work, in one day working steadily for 8 hours, and really working, not just holding that shovel up, is about 1,000 BTU's per day. That means that essentially each individual has at his service somewhere in the neighborhood of 900 slaves doing work for him. That doesn't mean people, of course; it means things and services. Everything that serves us directly or indirectly is a product of energy. The manufacturing or service process is guided by workmen, yes, but the level of productivity that makes the thing or service we buy economically attainable is its energy input. If one plots, for example, the gross national product per capita of a nation against its per capita energy use, one finds that the points cluster around the 45° line. The USA is way up at the top both in productivity and energy use. Some of these others are clear down here at the bottom. When we examine the spread about the 45° line, we find that some countries used less energy for a given productivity than others. Switzerland, for example, uses considerably less energy per capita

for a given product output than the USA does because theirs is almost entirely highly skilled, high technology industry whereas we make a lot of steel. We also make a lot of aluminum. We do a lot of conversion of primary raw materials into secondary industrial feed products, if you will. And this consumes more energy. But the fact remains that regardless of these deviations the standard of living is tied intimately to the amount of energy we use per person. Now what this says is that if we cut back the amount of energy we use per person, we inevitably cut back the material standard of living. We cut back the number of jobs that are available. You don't use the energy so you don't need the miners to mine the coal or the business and service people who served those miners. What I am really suggesting is essentially that when one looks at the second and third tier effects of conservation, one has to be prepared for some rather drastic changes in our people relationships and in our people approaches and in our people institutions. When I really want to be nasty to my conservation friends, I say, "Look, you're a bunch of hypocrites. You go around talking about turning off lights, turning off toothbrushes, and turning down thermostats--small stuff. When I find you down at the legislature fighting as hard as you know how to make it a felony to purposely build an obsolescence into any product including automobiles, I'll believe you're a conservationist." Then I will add, "I hope that you think about it a long time before you go down and do it."

If one were to take this approach one could build an automobile, as you all very well know, that could last essentially trouble free for a period of 15 years instead of two. I'm ignoring style but I suspect that style is going to be one of those things that one will

have to ignore more and more. One could do this -- it would conserve raw materials, it would conserve human effort, it would conserve really large amounts of energy, and boy, what it would do to jobs. Not only in the automobile industry itself, but in all of the primary industries that feed the automobile industry and in all the service industries that serve those people that work directly or indirectly in the automobile industry. Anyone who would carelessly move into this complex situation in a serious way would be committing a very major societal error.

On the other hand, there is no question in my mind but what this is going to be essential down the line. Somebody is going to wake up one of these days to the fact that he is working five days a week and that he could have exactly the same material well being working only a half day a week. It isn't often that I agree with Ralph Nader but he made the comment sometime ago that actually one could produce, one could supply people, with all of the things they now have on about 1/5 of the amount of labor that is now put in, if one were to wipe out this business of building in obsolescence. Now those figures are probably faulty at least but the basic argument can not be brushed off. Think about it because these are things that are coming. These are the things the students you are teaching now are going to have to face in the next 25 years. How you prepare them to meet this kind of accelerated change I must admit I don't know. If I did, I'd probably be somewhere else doing something about it because I think this indeed lies at the heart of the national future. It's a challenging time! I tell my own students, "I think you are in for an awful rough time for the next 25 years but one thing I can guarantee you and that is that you're not going to be bored."

655